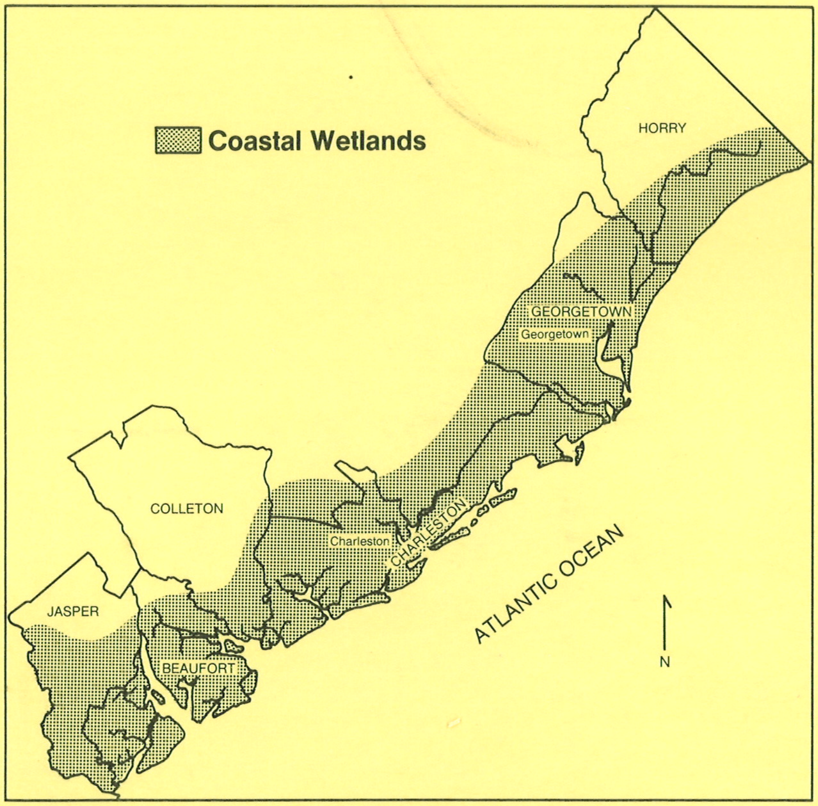
NOAA Estuary-of-the-Month

Seminar Series No. 12

Barrier Island/Salt Marsh Estuaries, Southeast Atlantic Coast: Issues, Resources, Status, and Management

August 1989



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NOAA Estuarine Programs Office

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Seminar Series No. 12

Diagnosis and Prognosis - Barrier Island/Salt Marsh Estuaries, Southeast Atlantic Coast: Issues, Resources, Status, and Management

Proceedings of a Seminar
Held February 17, 1988
Washington, D.C.

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Sr., Secretary

National Oceanic and Atmospheric Administration
John A. Knauss, Under Secretary

NOAA Estuarine Programs Office
Virginia K. Tippie, Director

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION,
U.S. ENVIRONMENTAL PROTECTION AGENCY,
AND
U.S. FISH AND WILDLIFE SERVICE

PRESENT AN

ESTUARY-OF-THE-MONTH SEMINAR

ON

THE DIAGNOSIS AND PROGNOSIS OF THE BARRIER
ISLAND/SALT MARSH ESTUARIES OF THE
SOUTHEASTERN ATLANTIC OCEAN

WEDNESDAY, FEBRUARY 17, 1988

PREFACE

These proceedings represent the presentations made at a seminar on Barrier Island/Salt Marsh Estuaries of the Southeastern Atlantic Ocean which was co-sponsored by the National Oceanic and Atmospheric Administration's Estuarine Programs Office, the U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Many issues concerning the health and value of this estuarine system are considered in these papers which deal with subjects ranging from geology to ecology and to system inter-connections. This volume is a kaleidoscope of information through which we can see those areas in which we are knowledgeable and those in which additional data are needed. Many questions are addressed and many more are posed by the participating investigators. These proceedings are designed not only to report the various presentations but also to stimulate future avenues of investigation.

The NOAA Estuarine Programs Office (EPO) wishes to thank Dr. James J. Alberts and Dr. James P. Thomas, who coordinated this effort, and all those who traveled to the meeting, prepared papers, and commented on the final edited version. EPO welcomes your comments or suggestions on this or any other volume in this series.

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INTRODUCTION

The coasts of Georgia and South Carolina are distinguished by their barrier islands and extensive wetlands (Figs. 1 and 2), which are dominated by salt marshes of smooth cordgrass, *Spartina alterniflora* (Loisel.). These marshes form an interface between the ocean and the numerous rivers which bring freshwater and terrestrially derived matter to these systems. Though only about 200 miles in length, these marshes comprise 43% of the salt marsh acreage of the entire east coast of the U.S. (Alexander, et al., 1986). Thus, they provide an extensive band of habitat which supports a large and economically important fishery, as well as acting as a buffer which protects the mainland by moderating the forces of ocean storm waves and tides. It is these systems which we wish to explore and explain in this volume so that we may share our understanding of their importance and the potential dangers inherent to them.

The marshes are one of the most productive ecosystems known to man. They convert atmospheric carbon dioxide to reduced carbon compounds at a rate of approximately 1400 g C/m^2/year (Pomeroy and Wiegert, 1981), which rivals the production rates of tropical rain forests and is greater than those found in cultivated crops in our most productive fields. This fixed carbon is not directly utilizable by man, but is the basis for a diverse food web with many of its consumers being commercially important species such as shrimp, crabs and numerous fin fish. It is also believed that this carbon may be an important source of nutrition for the nearshore coastal areas of the South Atlantic Bight, the oceanward extension of these systems.

The barrier islands, which are relatively recent geological formations, and the marshes formed behind them are dynamic and continually changing. The extensive river systems which bring sand and clays from the mainland continue to supply the system with basic building materials. The currents of the nearshore, winds and storms unceasingly shape and alter the islands and the marshes. Upon this long time scale pattern of change, the shorter term cycles of production and death of marsh biota are superimposed, and at the intermediate time scale are the processes brought to the marsh by man's activities.

Population centers continually shift in response to economic and social perturbations. By the year 2000, it is predicted that 75% of the U.S. population will reside within 50 miles of the coast (Schubel, et al., 1986). In Georgia alone, demographic predictions for the six coastal counties indicate a 40% population increase between the years 1980 and 2000 (Wagner, 1983). These people will want to use the coast for recreation, habitation, commerce, industry, waste disposal, etc. Yet, it has been demonstrated time and again that too much usage of coastal systems damages the very entity which has drawn the population. Often, this damage appears to be irreparable.

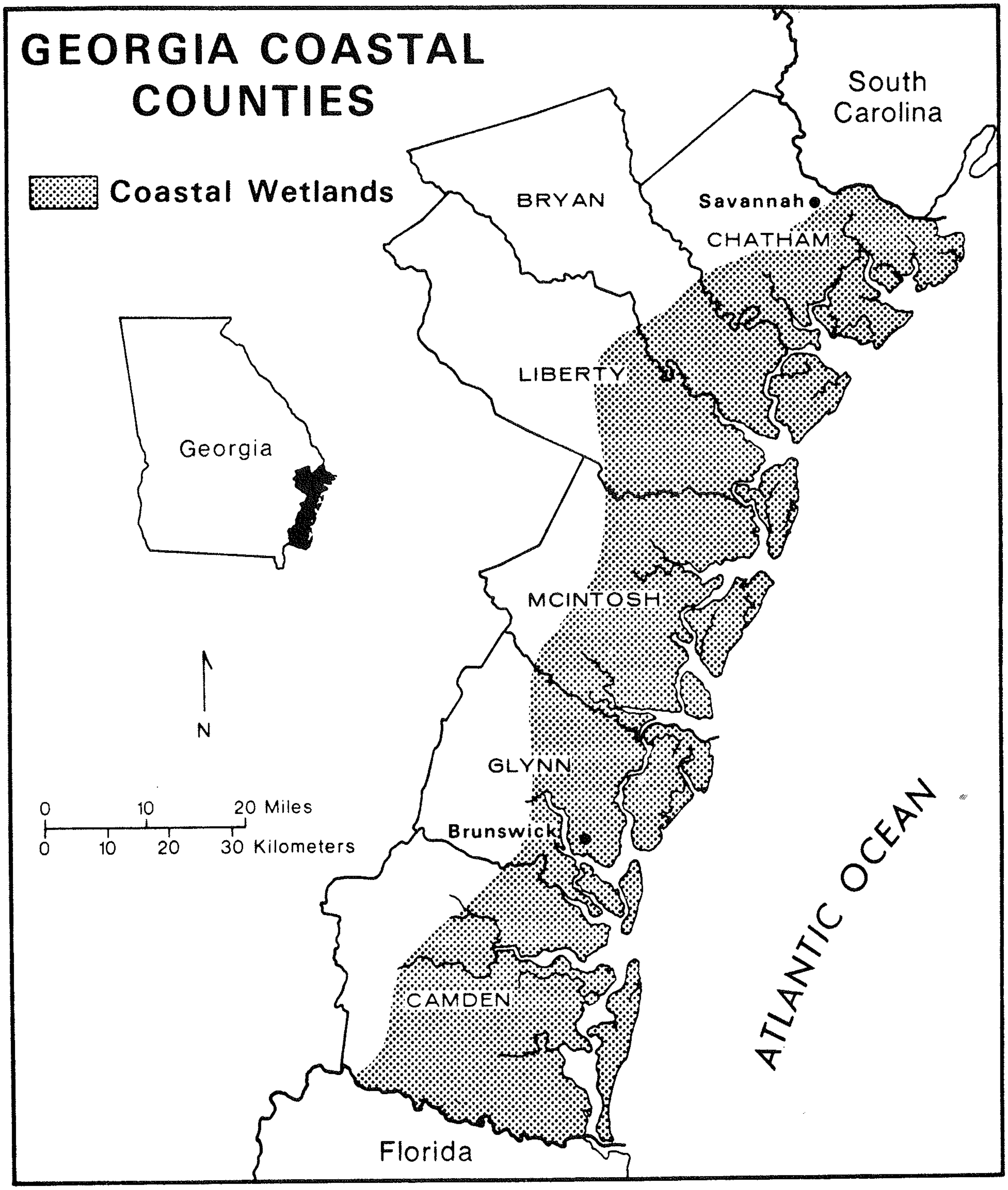

FIGURE 1. GEORGIA COASTAL COUNTIES AND WETLANDS.

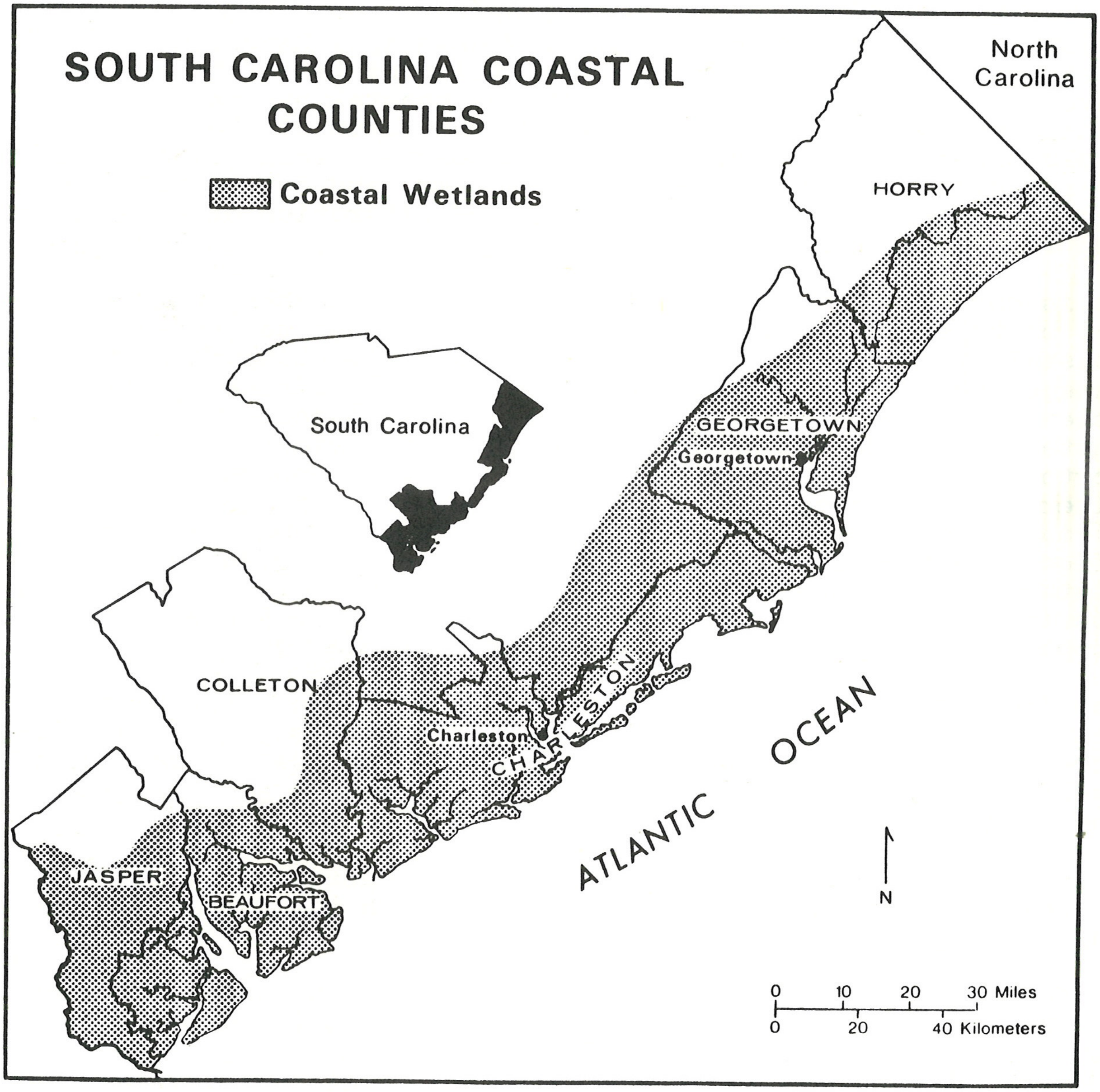

FIGURE 2. SOUTH CAROLINA COASTAL COUNTIES AND WETLANDS.

Increased coastal populations and increased demands for usage of the resources at the coast are not the only threats to these systems. As stated earlier, the river systems bring material derived from their watersheds, which is initially deposited into these marsh systems. Figure 3 is an illustration of the watersheds of the rivers which influence these coastal marshes. It is obvious from the figure that half of the state of Georgia, which is the largest state east of Mississippi River, all of the state of South Carolina and about a third of the state of North Carolina can impact on a small band of coastal marshes. Thus, pesticides or fertilizers applied on the farms of these states could end up in the estuaries of the coasts. Industrial usage over a wide area may impact these systems, and not to be minimized are the potential problems of alteration of water flow and removal of groundwater.

It is obvious that uncontrolled abuse of the coastal waters can not be tolerated, and many laws currently exist to protect coastal systems. However, the problems confronting the wise management of these coastal ecosystems are a combination of scientific, social, economic and political issues. For instance, how do you convince a group of individuals in western North Carolina that the introduction of some compound or alteration of water flow, which will greatly improve their local circumstances, should not be allowed because it will adversely affect individuals living 300 miles away on the coast of another state? These types of situations will increase in occurrence as populations and usage increase, and they must be answered if proper management of the system is to be achieved.

Man does not manage ecosystems. One is naive to think that it can be accomplished. Man manages man and the usages to which an ecosystem can be exposed. The demands on the coastal marshes of Georgia and South Carolina will only increase by all economic and demographic indices.

Therefore, the challenge is to control the usages of these systems so that they are not lost along with their benefits to our society.

In following chapters, we hope to discuss the natural processes of the marsh ecosystem and what is known of their function. We also wish to discuss the impacts to which these marshes have already been exposed and those which are still forthcoming. Our purpose in this exercise is to examine what has been learned in the years of scientific study of the marsh, what we know and can predict of a marsh's response to further use and abuse; and finally, how we can proceed to use the best information and techniques to manage man's usage of the marsh systems, thus, optimizing the ecosystems' usefulness without injuring it.

The salt marshes of South Carolina and Georgia are relatively unimpacted by the standards of many areas of this country. However, the demands are increasing and increasing rapidly.

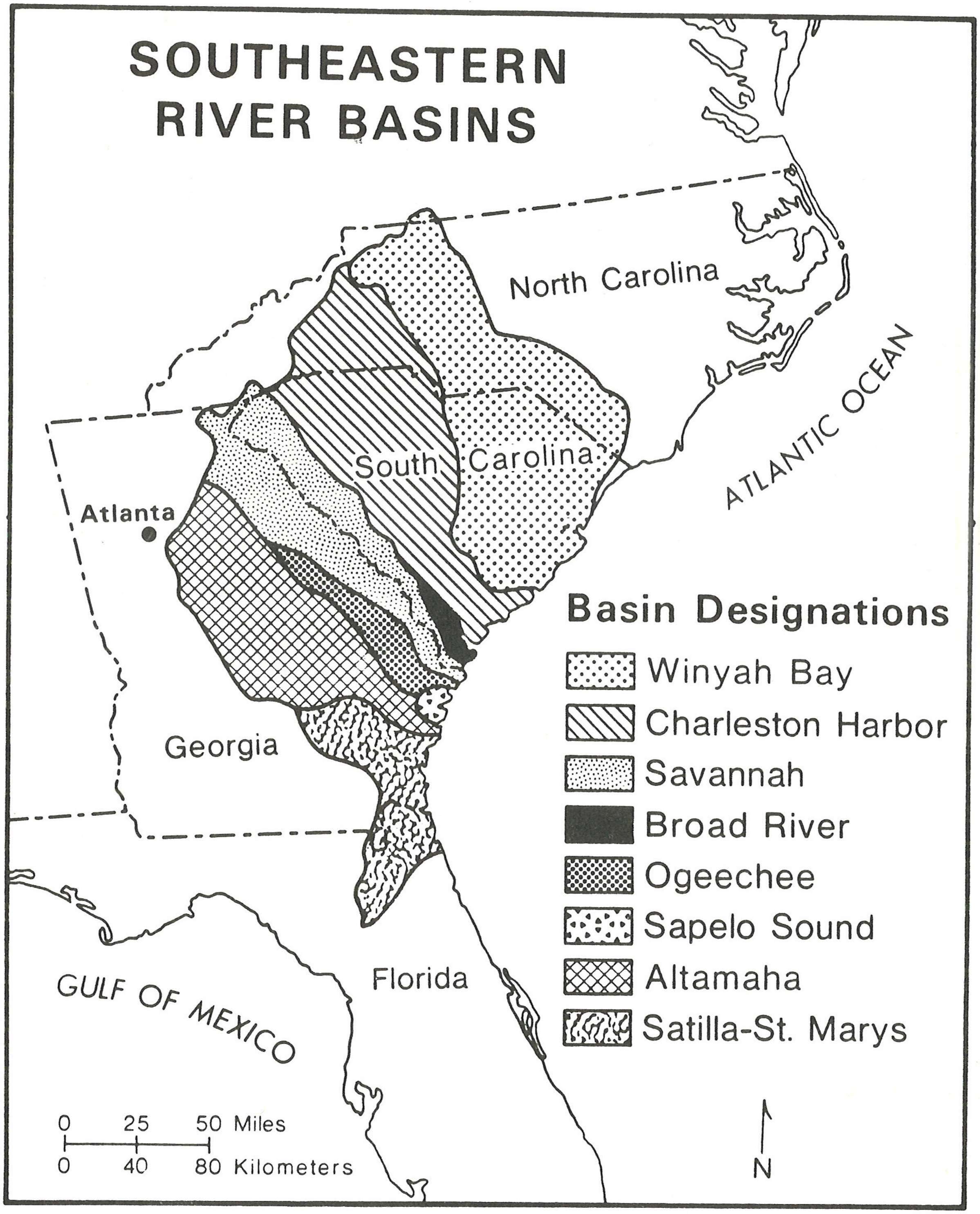

FIGURE 3. WATERSHEDS OF RIVERS ENTERING THE SALT MARSH ESTUARIES OF GEROGIA AND SOUTH CAROLINA.

We hope that through enlightened discussions between scientists, managers and the lay public these impacts can be minimized and these ecosystems can be preserved to function as they have historically, while still serving the reasonable usage of today's and future populations.

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ESTUARIES OF SOUTHEASTERN U.S. AN ECOLOGICAL OVERVIEW

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Estuaries in the southeast have a number of characteristics in common that are significant to their health and functions. They are situated on a coastline of rising sea level that contains a large amount shifting fine sediments, principally clays. These clays support the development of the intertidal marshes that make up about 75% of the area - three times as much intertidal marsh as permanently submerged water. Forty per cent of the total area of salt marshes on our east coast is in two states, Georgia and South Carolina. Not only is the area occupied by the estuarine water much smaller than the intertidal marsh area, but it takes the form of dendritic tidal creeks, so there is intimate contact between the marsh and the estuarine water, with significant amounts of water moving in and out of the marsh twice daily (Figure 1). The tides in the Georgia bight have the greatest amplitude of tides anywhere south of Cape Cod, so there is a lot of tidal energy translated into water movement in the southeastern estuaries. This impressed the scientists who began studying salt marshes in the southeast in the 1950's, and they looked for impacts of this water movement on biological processes.

The Odums, E. P. and H. T., suggested that the water was a circulatory system at the ecosystem level and that the tide was providing what they termed an energy subsidy to the marsh. The water brought inorganic nutrients such as nitrate and phosphate, into the marsh, and according to their hypothesis, removed organic matter that had been fixed there by the grass, delivering it to the estuary where it would be used by animals that have specialized in eating detritus rather than living plants (Odum and de la Cruz, 1963). E.P. Odum and students such as Alfred Smalley, Edward Kuenzler, and Armando de la Cruz, went on to develop the concept of the detritus food web and the concept E.P Odum called "outwelling." According to the outwelling hypothesis, the marshes synthesize excess organic matter that moves out into the estuary and perhaps into the nearshore ocean, providing food in the form of detritus for the animals living there (Odum, 1980).

The term, outwelling, has caused some confusion and misconceptions, because it sounds much like another term, upwelling, that is commonly used to describe the upward movement of inorganic plant nutrients in the ocean in places like the coasts of California, Peru, and South Africa. But by outwelling Odum meant the movement of organic, not inorganic, materials out of the marsh, or perhaps out of the estuary into the coastal ocean. Odum had found that the productivity of the marsh grass

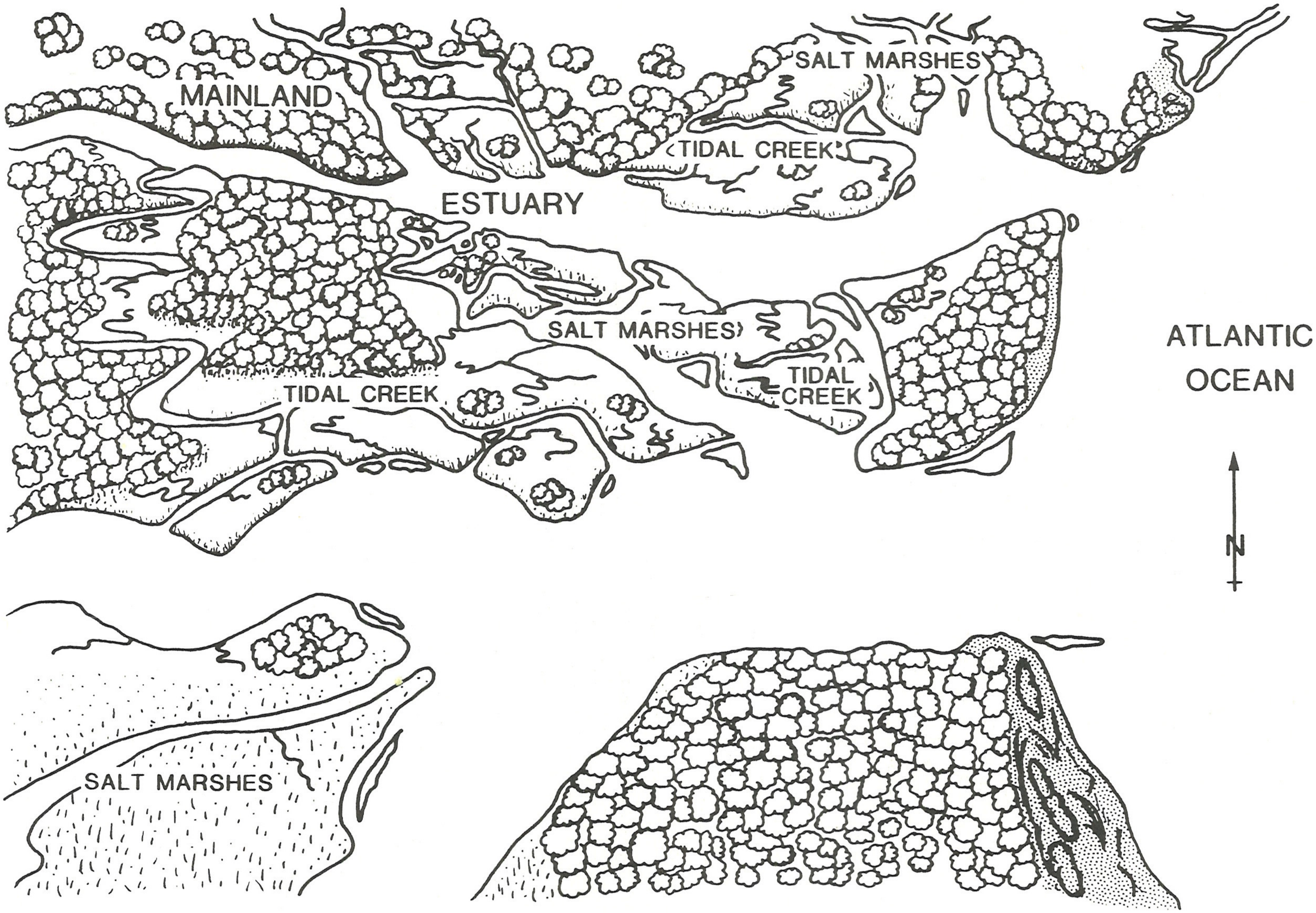

FIGURE 1. MAJOR PHYSICAL FEATURES OF THE SOUTHEASTERN COAST. BARRIER ISLANDS ALONG THE OCEAN FRONT PROTECT COASTAL LAGOONS LARGELY FILLED WITH INTERTIDAL SEDIMENTS. THE SEDIMENTS SUPPORT MARSHES CONSISTING LARGELY OF ONE SPECIES OF CORD GRASS. TIDAL ESTUARINE WATER ENTERS AND LEAVES THE MARSH THROUGH AN EXTENSIVE SYSTEM OF CREEKS. MODIFIED FROM CLEMENT, 1971.

was very high - like a field of sugar cane, which it resembles. He and his students further found that only about 5% of that grass was consumed by grazing insects while it was still alive. The rest simply died in the autumn, down to the surface of the sediment, and some of the dead grass could be seen dirfting around and breaking up into detritus. So the original 1960's vintage Odum view of the southeastern estuaries was of a system in which the production of organic matter was mainly a function intertidal marsh grass which was converted to detritus and supported a food web of detritivores. Those detritivores, in turn, supported commercial and sport fisheries, while the detritus itself contributed to the support of shellfish.

Other investigators, such as Dirk Frankenberg and his student, Eileen Setzler, were showing that the Georgia marshes were "nursery grounds" for a number of commercial and sport fish and shellfish. These included shrimp, menhaden, and several sport fish species. Both shrimp and menhaden enter the estuary very early in their life history and spend the warm, productive summer months feeding and growing in the small tidal creeks where food is plentiful and there is protection from many predators. A number of sport fish have similar life histories. Blue crabs also spend summers in the salt-marsh creeks, moving into the marshes with the incoming tide and returning to the creeks at low tide. So the estuaries and their extensive intertidal marshes were found to support coastal ocean fisheries as well as estuarine fisheries, and this was presumably supported by the detritus food web originating with the marsh grass.

Subsequent work has added many details to this picture, some of which change it quite significantly, while others open questions yet to addressed. In the 1950's, while Odum and his students were working, I was measuring the productivity of the single-celled algae that live near the surface of the intertidal sediment in the marsh. They were not than one fifth as productive as the marsh grass, so at the time Odum and others deemed them insignificant to the ecosystem. In the 1960's, J.P. Thomas (1966) measured the productivity of the phytoplankton in the estuarine and coastal waters and found that it was indeed very high. At a mean production rate of a gram of carbon fixed in organic matter per square meter per day, it was nearly as productive as the coastal upwellings of the west coasts of North and South America. This, together with the intertidal algae, consituted a significant rate of production of micro-algae, albeit smaller than the rate of production of the marsh grass. And of course the area occupied by the grass was three times that of the estuarine water at low tide.

During the 1970's several new developments changed the picture a bit further. Evelyn Sherr (then Haines) used the geochemical method of measuring the ratio of ordinary carbon-12 to naturally occurring heavy carbon-13 carbon-13 to follow food chains from their source. Because of differences in their biochemistry, the carbon-13 of the marsh grasses (a C_4 plant) is significantly different from that of the phytoplankton and the algae (mostly C_3) on the marsh sediments. Animals, it turns out, really are what they eat - they preserve very nearly the carbon-13 of the plants they assimilate into their own body tissues. So it was possible to measure the carbon isotope ratio of estuarine animals and say what they had been eating, whether detritus from the grass or phytoplankton and other micro-algae (Haines and Montague, 1979). There have been controversies and some refinements of technique since Sherr's early work, but we now believe that she was essentially correct in her findings. These were that the organisms in the marsh itself were largely eating detritus and the microorganisms on it, but the animals in the estuary, even the small tidal creeks, were largely eating micro-algae: phytoplankton the microflora on the intertidal sediments. This was a blow to both the concept of the detritus food web as the major one in the estuaries and to the outwelling hypothesis. Most of the grass in the southeastern estuaries, it seemed, did not move very far before it was utilized.

Just last year, still another line of evidence appeared to validate the conclusion. In collaboration with R. E. Hodson and M. A. Moran, I sampled the lignin in coastal ocean waters off Georgia to try to improve our understanding of the movement of the coastal water on the continental shelf. Lignin is a useful tracer for several reasons. Since it is not produced by any marine plants, it is a true tracer of fresh and estuarine water. By chemically dissecting the lignin molecules that we have collected from ocean water, we can estimate how long the lignin has been drifting in the water, and we can tell from its chemical signature whether the lignin originated from salt marsh grasses or from trees in fresh-water swamps upstream. We can trace lignin all the way out across the 70 mile-wide continental shelf to the Gulf Stream, but it is just that - a tracer. Most of the lignocellulose has been utilized by bacteria before it leaves the estuary.

So if the marsh grass is largely utilized in the marsh itself, how is it utilized? S.Y. Newell, Barry and Evelyn Sherr have studied the decay process. A significant part of it occurs while the grass is standing dead in the marsh and that decay process is the work of fungi. Once the grass and stems fall into the tidal water, the decay process is largley completed by bacteria. Hodson and Moran have studied the degradation of the lignocellulose of the marsh grass and find that it is converted to bacterial biomass with an efficiency of about 30%, which is very good for refractory particulate material. Yet, even at that level of efficiency there is a substantial loss, because the bacteria are largely consumed by protozoa, also about 30% efficient, and the protozoa must be consumed by something a bit larger before you have something that will be food for shrimp or fish. As a general rule, with few exceptions, animals eat food that are not less than one tenth of their own body size. This means that a food chain that begins with bacteria must have several steps before it reaches large fishes. And each step takes a toll in lost energy that goes off as heat to the environment (Figure 2). So we are beginning to think that the detritus food web, while very interesting, is perhaps not very efficient, and that the phytoplankton and other algae which can be consumed directly by shrimp and fishes or at least by their immediate food organisms, may indeed be a more significant part of the fishery food chain, in spite of the fact that there is more production of grass than of algae in the estuary (Pomeroy and Wiebe, 1987).

Another line of research also raised questions about the outwelling hypothesis. Investigators in several east coast estuaries attempted to develop input-output budgets for materials, both organic matter and inorganic nutrients. This was done in Georgia, South Carolina, Virginia and on Long Island in New York. Making such a budget is challenging, and one can debate the precision of some of the early attempts. The results were by no means uniform. The investigators on Long Island found that their marsh was taking in phytoplankton from Long Island Sound and consuming it (Woodwell et al., 1977; 1979) while the Georgia investigators found refractory organic matter, such as lignin and humic acids, leaving the marsh and moving down the estuaries (Imberger et al., 1983). Was the marsh a producer or a consumer? Was the Long Island marsh really different from the one in Georgia in some fundamental way? Careful scrutiny of the methods used and the data gathered does not suggest that these important differences were the accidental result of inaccurate research.

While that question has not been completely resolved, some interesting evidence has been developed by R.G. Wiegert who began making mathematical simulation models of the salt-marsh ecosystem in 1974. Making a model of something as complicated as a salt marsh ecosystem is a real challenge. Some scientists say you can't do it. But Wiegert did it anyway, and the models went through may generations. Each model told us something unexpected that sent us back to the estuary and the marsh to do more research to test the predictions. One of the early models suggested that there was an export of organic matter, and that it was in the form of living animals (Wiegert et al., 1981). This has been at least partly validated with observations of the production of shrimp, blue crabs, and fishes that grow in the estuarine marshes and leave it as young adults. The most recent model (Wiegert, 1986) again tells us something interesting. Any ecosystem can have one or more stable states, and once in a stable state it will tend to remain there unless perturbed. The salt marsh can have two possible stable states. In one the marsh exports organic matter and also accmulates it slowly in the sediments. In the other the marsh consumes organic matter that is imported from the estuary with the tide, and it consumes organic matter that has accumulated in the sediments. Wiegert

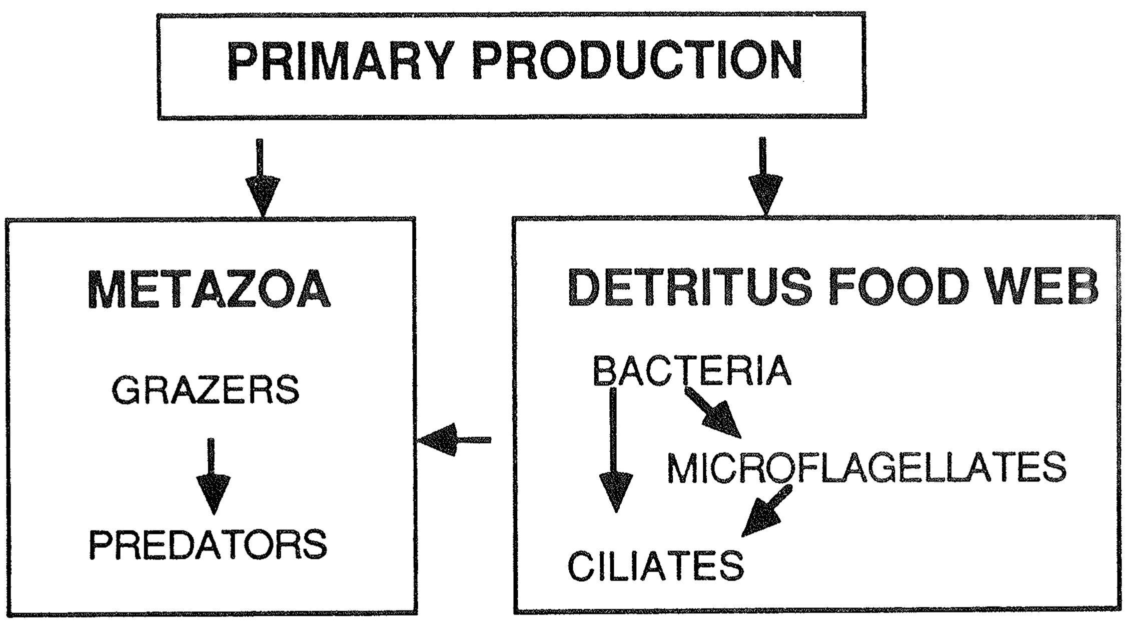

FIGURE 2. ALTERNATIVE PATHWAYS FOR THE FLOW OF ENERGY FIXED BY PHOTOSYNTHESIS IN SOUTHEASTERN ESTUARIES. THE MANY ENERGY TRANSFERS IN THE DETRITUS FOOD WEB RESULT IN LESS ENERGY TRANSFER TO FISHES AND SHELLFISH THROUGH THAT ROUTE.

believes that the Georgia marsh-estuary interaction is in the producer stable state most of the time. But does it switch? Is the Long Island marsh usually in the consumer stable state? These are significant questions, the answers to which will improve our ability to manage our southeastern estuaries.

These recent findings neither prove nor disprove that there is "outwelling" from our southeastern estuaries into the coastal ocean. It says that the organic material that is outwelling, if indeed it is, probably is refractory lignin and humates which may have come down the rivers as well as from the marsh grasses. Charles Hopkinson has made measurements of the respiratory rate of the microorganisms in the sediments and water of the coastal ocean off Georgia and he believes that there is more respiration than can be supported by the presently known rates of photosynthesis in the coastal water. While this suggests that there must be some outwelling of organic materials from the estuary, it is based on measurements that are difficult to extrapolate to the entire coast with precision. It would be useful to have some direct measurement of the outwelling organic matter. Unfortunately, it is technically very difficult to measure the net exchange of materials at the inlet of an estuary, because you are measuring a very small difference between several pairs of very large numbers, the amounts of the materials in the water and the amount of water itself. Moreover, most export probably is associated with periodic storm events, so occasional sampling on nice days will miss most of the action. So the outwelling hypothesis with respect to the estuary-ocean exchange remains to be falsified or substantiated.

The most important role of the marsh areas may be a very different one than that postulated by Odum and his students. Rather than feeding the animals in the estuary, it is providing structure and stability for them. It stabilizes the sediments and provides good habitats in which they can hide from predators and feed on the micro-algae and on each other. That is a short, efficient food chain which can maximize the production of fish and shellfish.

Looking back over the rather short history of estuarine research in the southeast, we see a continual evolution of our concepts of how these systems work. Approximately every decade we experience the introduction of a significant new idea, based on new research technology, that significantly alters ecological theory. There is a lesson here for managers and lawmakers, one we have all heard before but tend to brush aside because we need something firm and substantial on which to base action. Science by its nature is an evolving discipline. Even old, mature disciplines like physics and chemistry are still subject to emerging new concepts that change the way we must deal with the real world. In a new, immature science like ecology the change is more rapid. Of course, at any moment in time we have to work with the knowledge we have. We make laws, we enforce existing law, and we grant research grants on the basis of what we know. Indeed, there will always be a lag of some years between what scientists are currently deciding is the best interpretation of new (and old) data and the implementation of those new perceptions into administrative action. This is as it should be. Where we have to be vigilant is in maintaining an awareness that there is always a need to keep up as nearly as possible with new advances. In this respect science and law are opposed in their method. Law builds on the establishment of precedent. Science constantly rebuilds. Thus, the administrator is faced with the implementation of existing laws and regulations in the face of constantly changing scientific perceptions of how the world works and how we should best protect our environment. This can lead to amusing or aggravating confrontations. It places demands on both administrators and scientists to communicate and interact. Having identified this problem, I offer no simple solution. We simply must cope continully by remaining aware that changes in science are always occurring, that validation of new ideas takes time, and everyone needs to communicate and to be as open minded as possible toward that kind of change. Forums such as this one are an important means to that end.

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GEOLOGICAL DEVELOPMENT OF THE GEORGIA COAST PAST, PRESENT AND FUTURE

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Introduction

The purpose of this paper is to provide the reader with (1) a brief description of the geomorphology and physical environments and processses associated with the geological development of the Georgia coast (and to most of the South Carolina coast, as well) and (2) an equally brief statement on the present and future human problems that have and probably will result from the interaction between these ongoing and, geologically long-term, physical processes and those of us intent on settling and developing the most dynamic portion of the coastal zone.

Of perhaps even greater concern is our potential for increasing the speed at which physical processes are modified to our detriment, e.g., accelerated sea level rise caused by the "Greenhouse Effect". The lack of a comprehensive plan to deal with coastal development, i.e., meaningful, hard-nosed zoning, in the face of sea level rise and "overdue" hurricanes suggest, at the very least, a pervasive and knowing disregard for the evidence.

Geological Setting

Coastal Georgia is bordered by a series of short, wide barrier islands separated by relatively deep tidal inlets. Extensive shoal systems are present seaward of the inlets and central portion of the islands (Figure 1).

The barrier islands are essentially lenticular bodies composed of dune and beach ridge sands overlying older nearshore and intertidal and channel deposits. Back barrier areas contain sands and muds that have been extensively reworked by tidal channel migration. Sediments of the inshore facies are composed of Holocene and reworked Pleistocene sands and muds. Relict deposits are present seaward of the inshore zone.

A total of 15 seperate islands comprise the 100 miles of coast between the Savannah and St. Marys rivers. Six of the eight largest islands are composite barriers consisting of a core of beach and dune deposits formed during the previous, and slightly higher, Pleistocene Silver Bluff eustatic sea level of approximately 35,000 years ago. Most of the islands are closely fronted by analogous deposits formed during the present, or Holocene, sea-level rise which began 15,000 years earlier (Figure 2).

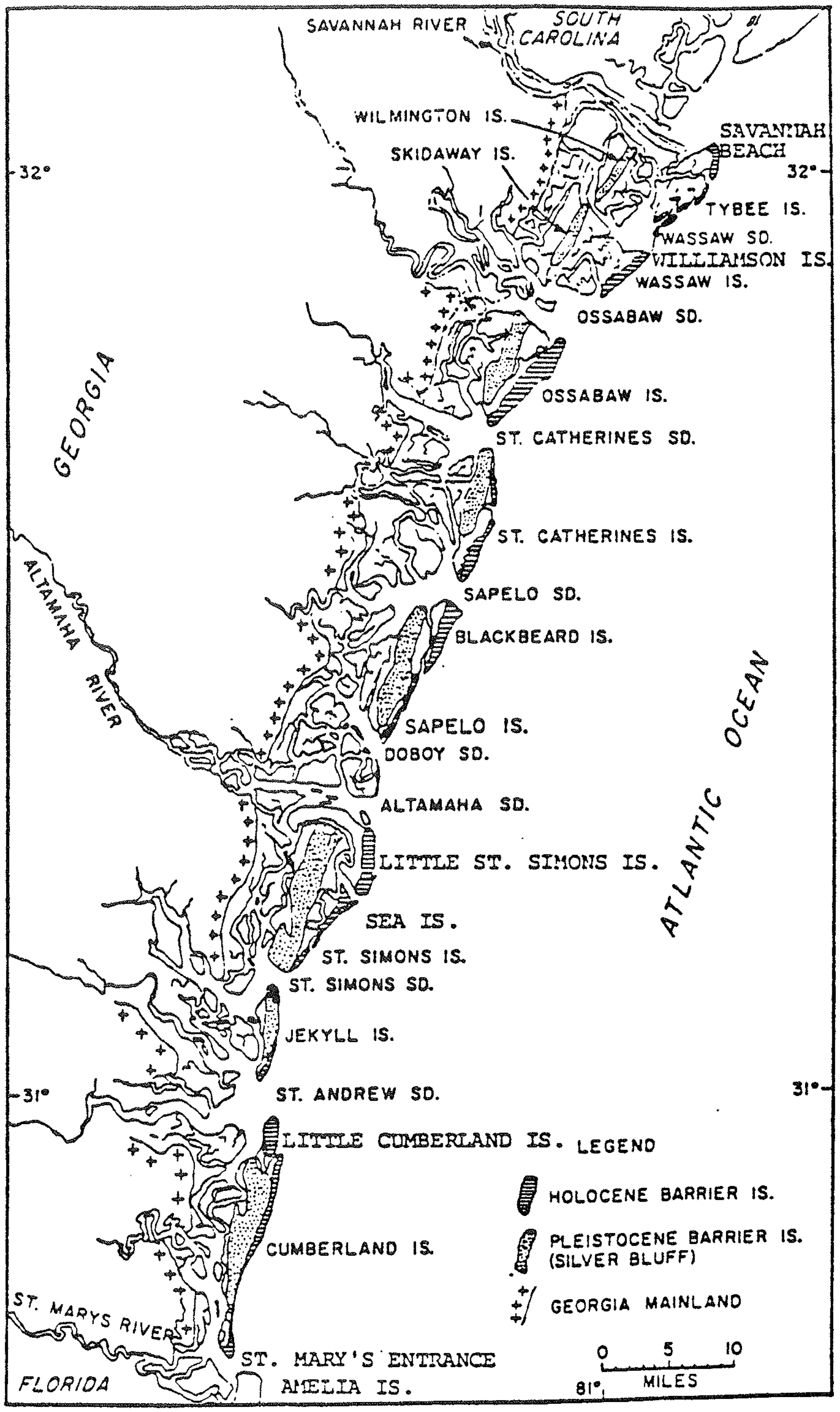

FIGURE 1. MAP OF THE GEORGIA COAST SHOWING LOCATION OF BARRIER ISLANDS, SOUNDS, AND MAJOR RIVERS.

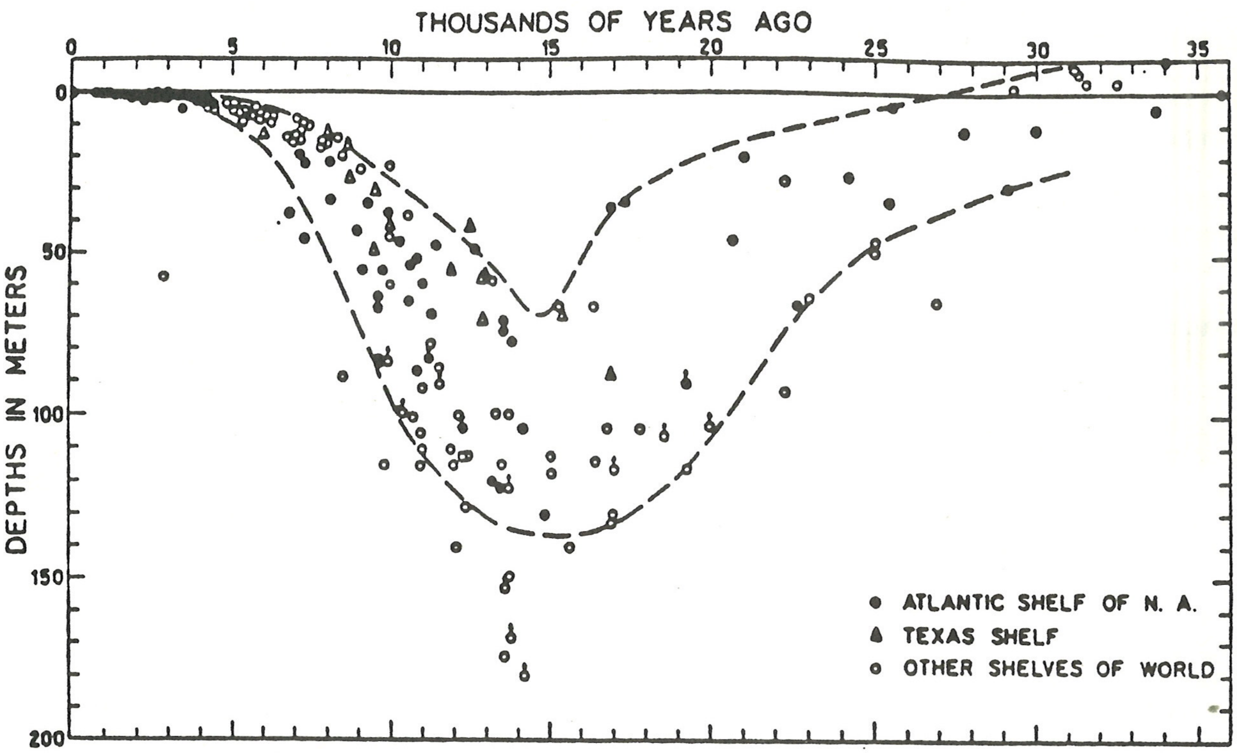

FIGURE 2. SEA LEVEL DATA FROM U.S. ATLANTIC AND TEXAS SHELVES COMPARED WITH DATA FOR OTHER SHELVES OF THE WORLD (FROM EMERY AND UCHUPI, 1972).

Tybee and Wassaw Islands are seperated from Wilmington and Skidaway Islands, their respective Pleistocene counterparts, by earlier deltaic outbuilding of the Savannah River. A genetically similar, but smaller, separation is present just south of the Altamaha River, at St. Simons Island, where Sea Island and Little St. Simons Island are the Holocene components. Salt marshes that formed contemporaneously with Pleistocene parts of the islands were reflooded during the Holocene sea-level rise, recreating an intricate system of tidal streams, creek, and marshes separating the barrier islands from the mainland.

Although Holocene and Pleistocene beach and dune sands are similar in texture, Holocene sands are light tan, unweathered, and composed mainly of fine, angular grains. Shell material is present in the upper zone. Well-defined beach-dune ridge complexes having no obvious soil zones further distinguish Holocene deposits. Surficial Pleistocene deposits generally have well-developed podsols and humate zones, and commonly are coarser grained. Interiors of the islands are vegetated primarily by oaks, pine, and palmetto forests and by a variety of dune grasses and shrubs along inlet margins and wide sandy beaches.

Marsh vegetation consists chiefly of smooth cordgrass (Spartina alterniflora) fringed by needlerush (Juncus roemerianus) spiked saltgrass (Distichlis spicata), and glasswort (Salicornia spp.) in higher areas. Except for dune ridges, which may be more than 15 m high, the barrier islands have relatively low elevations ranging from 4.5 to 7.5 m above MSL.

The islands have undergone substantial erosional and depositional modification since slowing of the Holocene transgression began about 5,000 years ago. Holocene constriction of inlets resulted in increased marsh deposition and decreased back barrier tidal prisms. Southerly extension of many barrier islands has occurred because of migration of tidal channels under the influence of predominantly south littoral currents. (See Figure 3).

Winds, Waves and Tides

Dominant onshore winds are from the northeast and southeast, whereas dominant offshore winds are from the northwest and southwest. Because of coastal configuration and a broad, shallow continental shelf, wave energy along the Georgia shoreline is low with wave heights averaging between 0.8 and 1.25 m.

The Georgia Coast is tide-dominated. Average tidal fluctuation is a little over 2 m and spring ranges of 3 m are frequent.

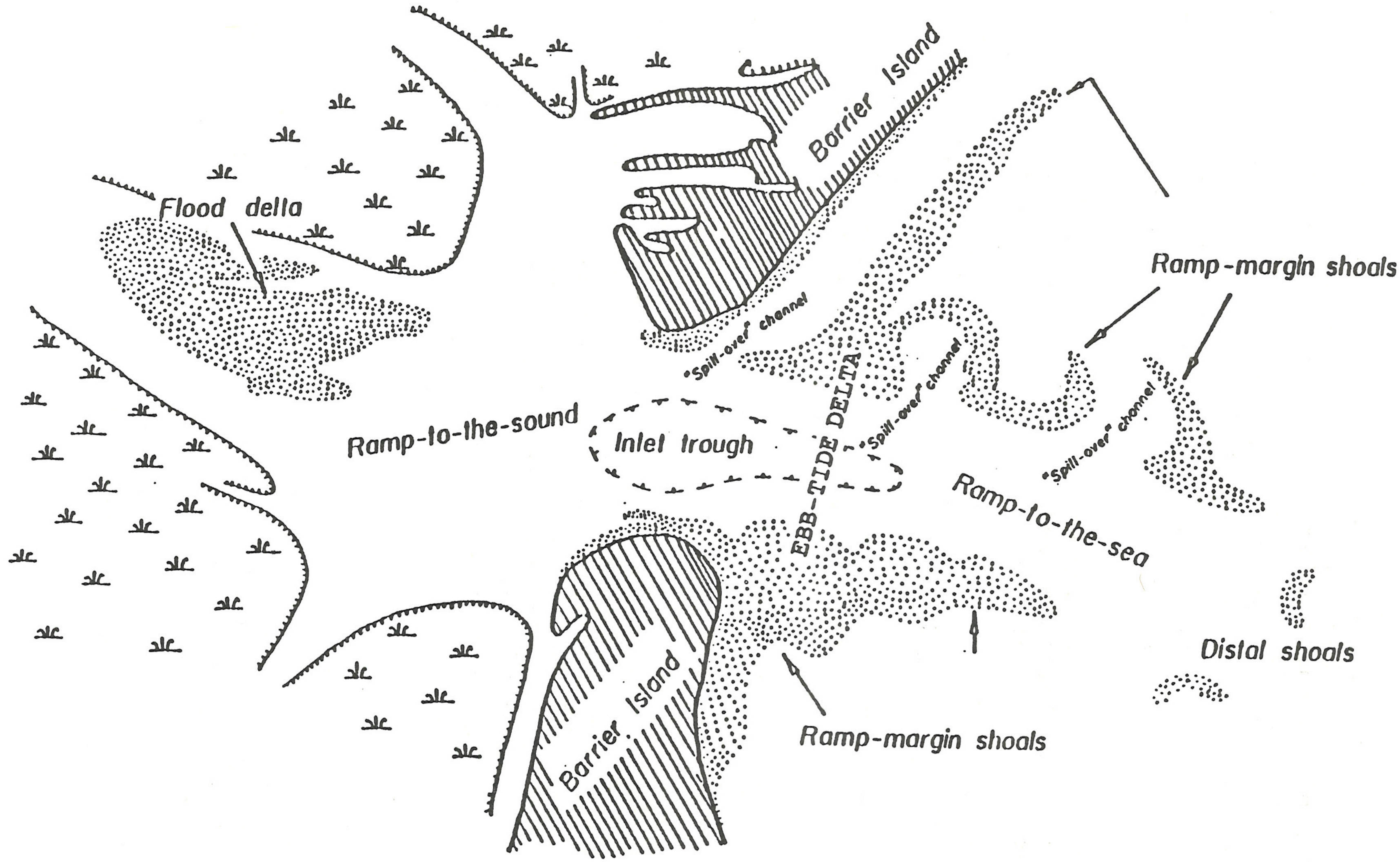

FIGURE 3. A DIAGRAMMATIC GEORGIA TIDAL INLET SHOWING PROMINENT GEOMORPHIC FEATURES SUCH AS THE EBB-TIDE DELTA, INLET TROUGH OR THROAT, AND THE MARGINAL SHOAL SYSTEM. ALONG THE GEORGIA COAST, FLOOD-TIDE DELTAS ARE USUALLY NOT WELL DEVELOPED. SEDIMENT NORMALLY MOVES ALONGSHORE AND THROUGH AND AROUND THE EBB-TIDE DELTA FROM NORTH TO SOUTH (FROM OERTEL, 1975).

Sounds, Inlets and Tidal Deltas

The presence of large coastal reentrants, or sounds, is characteristic of the landward portion of the Georgia Bight, a major physiographic feature extending from the Santee Delta in South Carolina to Jacksonville, Florida. Within the Bight, tides control the flux of passive organic/inorganic sediment that makes exterior (offshore) shoals and ebb-tide deltas (Figure 3). Seasonal wave climate modifies shoal and shoreline morphology and determines the direction and extent of alongshore sediment transport.

The geological development of the Georgia and South Carolina coast is prodoundly influenced by the large but cyclic storage capacities (tidal prisms) of the back barrier lagoons. Powered by the 2-3 m tides, nearshore waters are flushed in and out of the lagoons through the constricted inlet troughs (or throats) between the barrier islands. The sudden loss of carrying capacity upon entering the open ocean causes the exiting tidal currents to deposit the coarsest sediments just seaward of the inlet, thus forming an arcuate series of shoals collectively called an ebb-tide delta. Such features are characteristics of mesotidal (2-4 m tides) and macrotidal (>4 m tides) coasts. Intra-lagoonal, flood-tide deltas are more characteristic of microtidal (<2 m tides) regions; for example, the Texas and North Carolina coast.

The coastal sand-sharing system consists of the ebb-tide delta; the alongshore, downcurrent drift of sediment; and the adjacent dynamic beach and dune system. Under natural conditions, the ebb-tide delta is slowly skewed downcurrent and its southern component welds onto, and nourishes the northern, or upcurrent, portion of the adjacent barrier island. Thus, the inlet/along shore drift system passes, or shares, sand from upcurrent sources to downcurrent recipients. Any interruption of this flow of sand, such as inlet dredging, jetties, etc., results in starvation of downcurrent shorelines. While this scenario has ample evidence to substantiate its validity, at least one "interrupting" federal agency refuses to acknowledge their role in this regard.

From the foregoing the following generalities may be stated:

1. Interior salt marshes are dynamic repositories of clays and silts. Exterior shoals and ebb-tide deltas are dynamic repositories of sands and gravels.

2. Most fine sediment in the nearshore area is restricted by wind, wave and alongshore transport patterns to a zone seldom wider than 8-15 km.

4. Both coarse- and fine-grained material tends to move peristaltically down the coasts (southerly), and in-and-out of estuaries. Residence time in the estuarine/shoal systems

may be long or short term as acted on by diurnal, seasonal or extraordinary tidal storm events. Man-made perturbation such as dredging, filling, damming, soil erosion, and shoreline "engineering" are increasingly interrupting and compromising this dynamic down-the-coast, sand-sharing system, resulting in severe sediment losses from a) dredged material being disposed below normal wave-base, b) jetties, with no sand by-passing capability, c) armoring of shorelines, thus preventing new material from entering the system and d) damming of rivers.

History of Shoreline Change, 1857-1982

A study of the changes in the mean high water shoreline along the Georgia coast for the period 1857-1982 was carried out by Griffin and Henry in 1982 (Figures 4 and 5). The work was based on anaylsis of topographic, hydrographic and orthophotographic maps and controlled aerial photography. The results of the study is summarized as follows:

1. During the period from 1857 to 1925, in which several major hurricanes occurred in the late 1880's, approximately 80% of the Georgia coast prograded, due primarily to the great denudation of the Georgia Piedmont prior to soil conservation practices and to the damming of rivers for flood control;

2. In the interval from 1924 to 1974, the Georgia coast was characterized by dynamic stability; erosion on St. Catherines and Tybee/Little Tybee Islands was offset by deposition on Little St. Simons and Cumberland Islands, while each of the other islands maintained equilibrium;

3. During the period from 1957 to 1974, which was characterized by accelerating erosion rates and a major hurricane, most of the major barrier islands, nevertheless, maintained a dynamic stability;

4. During the interval from 1974 to 1982, partial photographic coverage of the Georgia coast indicated a continuation of erosion/accretion trends established prior to 1974, coupled with an apparent loss in linear extent of depositional sites along the shoreline.

Study results also indicate patterns of island rotation, spit cyclicity, island elongation, shifts about persistent nodal points, and southward migration. Such trends indicate that, presently, dynamic stability, marked by extreme local instability, characterizes 80% of the Georgia coast.

Georgia's Beaches and Barrier Islands - Some Facts and Figures Concerning Future Management of Georgia's Coastal Resources

As the crow flies, Georgia's coastline extends a little over 100 miles from the Savannah River to the St. Mary's River.

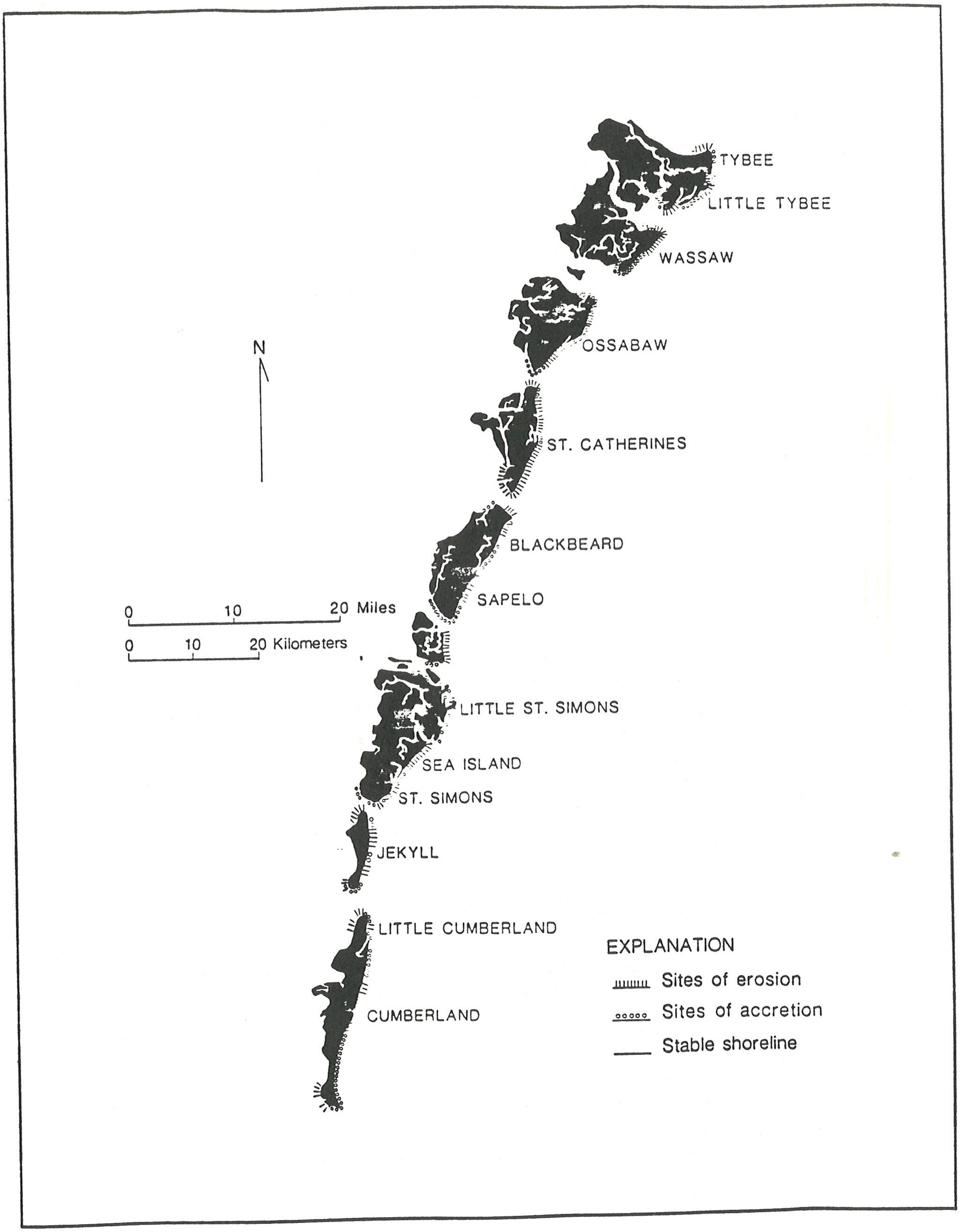

FIGURE 4. SUMMARY MAP OF EROSION/ACCRETION TRENDS OF THE GEORGIA COAST, 1924-1974.

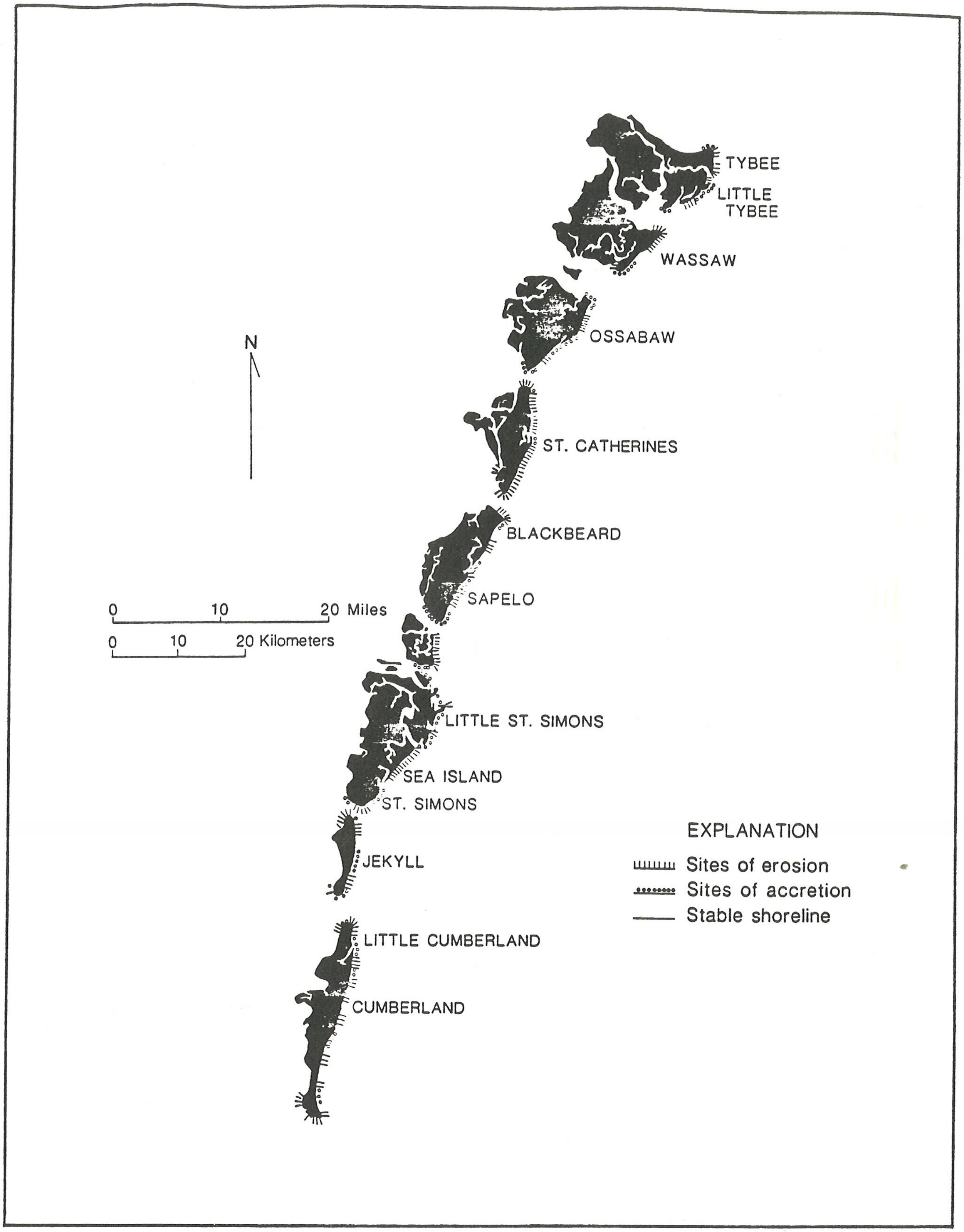

FIGURE 5. SUMMARY MAP OF EROSION/ACCRETION TRENDS OF THE GEORGIA COAST, 1954/57 - 1974/80/82.

Fourteen barrier islands provide approximately 90 miles of sandy beaches. Of these:

- 3 are national wildlife refuges (Wassaw, Blackbeard and Wolf)
- 1 is the State's first Heritage Trust preserve (Ossabaw)
- 1 is both a National Estuarine Sanctuary and a State wildlife refuge (Sapelo)
- 1 is a National Seashore (Cumberland)
- 3 are privately owned but undeveloped (St. Catherines, Little Saint Simons and Little Cumberland)
- 1 no longer exists as a barrier island as of March 1983 (Williamson)

The remaining 4 are accessible by causeway and are privately and commercially developed. The four islands, Tybee, Sea, St. Simons, and Jekyll collectively have 19 miles of beach or 22% of the total beach shoreline.

The Georgia coast has not had a major hurricane in 24 years (Dora 1964) or Camille-class hurricane in 90 years.

A study of the historical changes in the mean high water shoreline of Georgia over the past 129 years was recently published by the Department of Natural Resources (Griffin, M.M. and V.J. Henry, 1984). The results indicate that the basic causes of shoreline erosion are:

1. The worldwide rise in sea level (average 1'-2'/century);
2. Seasonal storms and hurricanes;
3. Man's activities, including channel dredging with offshore disposal of dredged material, jetty construction, shoreline structures, and damming of rivers.

The results also indicate that:

- For the most part, greatest shoreline change occurs along the northern and southern third of the islands.

- Most island shorelines show only slight net retreat, large oscillations (several hundred feet or more) have occurred in the past.

- During the past 77 years the greatest net shoreline retreat has occurred on Tybee, St. Catherines, Wolf, and Jekyll Islands.

- The long-term future trend of "natural" worldwide sea level rise dictates that shoreline erosion will probably worsen due, in large part, to human coastal modification.

- Where shorelines of the developed islands have been "fixed" by the emplacement of rock and cement structures, beach slopes have been flattened so that the time the beach can be "used" between high tides is greatly shortened.

- Erosion becomes a "problem" only when people and property are directly involved.

- Severe erosion problems, therefore, exist on Tybee Sea Island, St. Simons, and Jekyll--the only four developed barrier islands. Also, potentially severe problems exist in the St. Marys/Cumberland Island area

- Aside from common shoreline problems, some other important similarities are:

  1. All have major ports or harborts, with plans for major expansion including widening and deepening of the navigation channels.
  2. All are associated with major cones of depression caused by groundwater withdrawal. It has been recently suggested that this could lead to land subsidence and increased erosion.
  3. All are experiencing a tremendous growth in both resident and transient population with all of the attendant services and amenities.

Additional food for thought:

- It has been estimated that the 1980 coastal population of 320,000 will increase to over 420,000 by the year 2000.

- The majority of this population is or will be concentrated on or in the proximity of Tybee, Sea, St. Simons, and Jekyll islands, which together have only 22% of the total beach shoreline.

- Between April 1979-April 1983, 790 townhouse/condominium units were constructed on Tybee and St. Simons islands at a cost of $82 million dollars. During that time $4.4 million dollars of single family housing was constructed.

- Between 1980 and 1987, 15 marinas were constructed and more are in the offing. Several marinas have or will be significantly enlarged.

- To date the residents of Sea Island have spent approximately 6 million dollars for shoreline stabilization structures. In 1987, the Sea Island Company placed groins and beach nourishment along their recreational beach at a cost of nearly $600,000.

- Between 1974 and 1987, a total of $7,730,000 has been expended in an effort to provide the State a quality recreational beach on Tybee Island. The State/Federal cost sharing was 51%/49%.

- A very significant increase in the rate of rise of sea level has been forecast over the next century as the result of the accumulation of carbon dioxide (CO_2) and other fossil fuel combustion gases in the atmosphere which, in turn, causes a worldwide increase in the average annual temperature and consequent melting of glacier and polar ice caps. This phonomenon is called the "Greenhouse Effect" and because of it, worldwide sea level has been predicted to rise between 2 feet and 11 feet by the year 2100, or 112 years from now.

- A major problem in dealing with coastal erosion, both natural and man-related, and concurrent growth of coastal residential, recreational, industrial, and commercial development is that the State does not have a mechanism to coordinate the several agencies and institutions involved. Coastal Area Planning and Development Commissions are a start but several important planning and coordinating functions are missing. The Coastal Marshlands Protection Act of 1970 and the Shore Assistance Act of 1979 basically react to situations as they arise--they do not provide for either short or long term planning. The Shore Assistance Act and local zoning laws are often contradictory in their objectives. The development of a strong zoning ethic based on known and potential environmental concerns must be given the highest priority.

- A significant part of the dredged material removed from navigation channels is suitable for use as beach nourishment. For over a century this natural resource has been removed from the coastal sand-sharing system, deposited below wave base and lost forever to the system. Paradoxically, the channels suffer from too much sediment and the beaches from too little.

- In the Savannah Harbor alone, more than seven million cubic yards of sediment have been dredged annually since 1970. At the mouth of the St. Marys River, more than 350,000 cubic yards (270,000 m^3) of sediment are dredged yearly to facilitate navigation in the St. Marys Entrance Channel, and about the same amount is dredged from the Kings Bay Entrance Channel. At Brunswick Harbor about a million cubic yards have been dredged annually in recent years.

- In their natural state, the ebb-tidal deltas that characterize Georgia inlets only temporarily intercept littoral drift before transporting sediment downcurrent. However, navigation projects involving channel dredging and jettied entrances, such as at Savannah Harbor, Brunswick Entrance Channel, and St. Marys Entrance, significantly interrupt transport. The loss of dredged sediment from the littoral transport system results in severe sediment starvation of shorelines south of these inlets.

- The side effects of jetty construction include: (1) a drastic alteration of the ebb-tidal delta system; (2) initially intensified deposition adjacent to the upcurrent jetty; (3) probable elimination of downcurrent sediment transport; and (4) development of a vast sediment sink seaward of the jetties.

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LEVEL OF CONTAMINATION IN ESTUARIES OF THE SOUTHEASTERN ATLANTIC COAST OF THE UNITED STATES

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Abstract

The National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends Program is monitoring levels of chemical contaminants in the coastal United States. At 50 Benthic Surveillance sites fish and sediments have been collected since 1984 and at 150 Mussel Watch sites bivalves and sediments have been collected since 1986. All samples are analyzed for a suite of trace elements, chlorinated pesticides, polychlorinated biphenyls, and polyaromatic hydrocarbons. A recent summary of that data (NOAA, 1987) shows that high levels of chemical contamination are associated principally with population centers. Except for the curiously high levels of arsenic in oysters, contaminant levels in oysters at none of the ten southeastern Mussel Watch sites nor in fish livers at any of the four southeastern Benthic Surveillance sites ranked among the upper ten percent on a national scale.

Introduction

The National Status and Trends Program of NOAA has been monitoring levels of chemical contamination in the coastal United States since 1984. In that year, the Benthic Surveillance Project began with the collection of fish and sediments at 50 sites around the country. That Project is carried out by scientists from the National Marine Fisheries Service (NMFS) and, specifically in the southeast by investigators from the NMFS laboratories in Beaufort, NC and Charleston, SC. The Mussel Watch Project began in 1986 with the collection of bivalve molluscs and sediment from 150 sites. That Project is implemented through laboratories at Texas A&M Research Foundation, Science Applications International Corporation, and Battelle Ocean Sciences. The Battelle laboratories conduct sampling along the Southeast Atlantic Coast. Both projects determine concentrations of the same suite of chemicals (Table 1) in surficial sediments and in tissues. A major difference is that the Benthic Surveillance Project collects and analyzes fish livers while the Mussel Watch Project deals with bivalves. In the southeast Atlantic and along the Gulf coast those bivalves are oysters; elsewhere mussels are collected. All sites are chosen in an attempt to gauge contaminant levels over general areas. Known "hot spots" of contamination are not sampled nor are sites located near waste discharges. The most recent NS&T report (NOAA, 1987) contains all the data for chemical contaminants in fish livers collected in 1984 and in bivalves collected in 1986.

TABLE 1. CHEMICALS MEASURED IN THE NATIONAL STATUS AND TRENDS PROGRAM

Major Elements

Al Aluminum
Fe Iron
Mn Manganese
Si Silicon

Trace Elements

Sb Antimony
As Arsenic
Cd Cadmium
Cr Chromium
Cu Copper
Pb Lead
Hg Mercury
Ni Nickel
Se Selenium
Ag Silver
Tl Thallium
Sn Tin
Zn Zinc

Polyaromatic Hydrocarbons

Acenaphthene
Anthracene
Benz[*a*]anthracene
Benzo[*a*]pyrene
Benzo[*e*]pyrene
Biphenyl
Chrysene
Dibenzanthracene
2,6-Dimethylnaphthalene
Fluoranthene
Fluorene
1-Methylnaphthalene
2-Methylnaphthalene
1-Methylphenanthrene
Naphthalene
Perylene
Phenanthrene
Pyrene

Sum of all polyaromatic hydrocarbons symbolized in text as **tPAH**

DDT and its metabolites

o,p'- DDD
p,p'- DDD
o,p'- DDE
p,p'- DDE
o,p'- DDT
p,p'- DDT

Sum of all DDT and its metabolites symbolized in text as **tDDT**

Chlorinated Pesticides other than DDT

alpha-Chlordane
trans- Nonachlor
Dieldrin

Aldrin
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Lindane (gamma-BHC)
Mirex

Sum of all non-DDT pesticides symbolized in text as **tChlP** (in most cases the chlordanes and dieldrin comprise the bulk of the **tChlP**)

Polychlorinated Biphenyls

PCBs at each level of chlorination from 2 to 9

The sum of all PCB congeners symbolized in text as **tPCB**

Contaminants in the Southeast

There are 14 NS&T sites in the southeast spanning the coast from Roanoke Sound in North Carolina to Biscayne Bay in Florida (Figure 1). One common characteristic among them with regard to chemical contaminants is that, with one exception, none of the sites contains oysters or fish which can be considered among the more contaminated when viewed from a national perspective.

Table 2 from NOAA (1987) lists the east coast sites that on a national scale are among the more contaminated. That listing is based on rankings of concentrations of chemicals such as that for total polychlorinated biphenyls (tPCB) shown in Figure 2. As explained in NOAA (1987) the rankings should not be accepted so literally that sites whose bivalves concentrations for any particular chemical rank close to one another are necessarily considered different in terms of that contaminant. This limit to the resolution for distinguishing among sites is due to the range of differences between means and to their variability as defined through analyses of three separate samples at each site. Differences among concentrations decrease as the concentrations decrease and the data yield better resolution between the highest concentrations and the rest than among concentrations which are not at high levels. The high concentrations were used to distinguish among sites and, as noted in the footnote of Table 2, a site was not considered along the more contaminated unless it ranked among the first 15 for three contaminant concentrations, or the upper ten for two contaminants, or the first five for one contaminant. Zinc and copper concentrations have not been used when ranking sites on a national scale because of the great difference between oysters and mussels in accumulating those metals. Regardless of site location all the oysters had higher concentrations of both metals than did any of the mussels. Because fish metabolize PAH compounds, they were not analyzed for the parent compound.

If it were not for the arsenic concentrations in oysters no southeastern site would have been listed among the more contaminanted. But because of arsenic (As) levels the two Charleston Harbor sites and the Cape Fear site are listed in Table 2. The reason for these relatively high levels of arsenic is not known, but is strongly suspected to be a consequence of local mineralogy rather than the activity of humans. One reason for suspecting mineralogy is that all five sites from Cape Fear, NC to Sapelo Island, GA are among the first six in As concentrations in bivalves (Table 3).

Table 3 also gives some sense of the relative levels of contamination among the southeastern sites. Oysters at three Mussel Watch Sites have total polyaromatic hydrocarbon (tPAH), silver (Ag), or tin (Sn) concentrations among the upper 25 of 143 sites on a national scale; and fish (spot) liver concentrations of total chlorinated pesticides (tchlp), other than DDT at one Benthic Surveillance site were, among the first 20 of 43

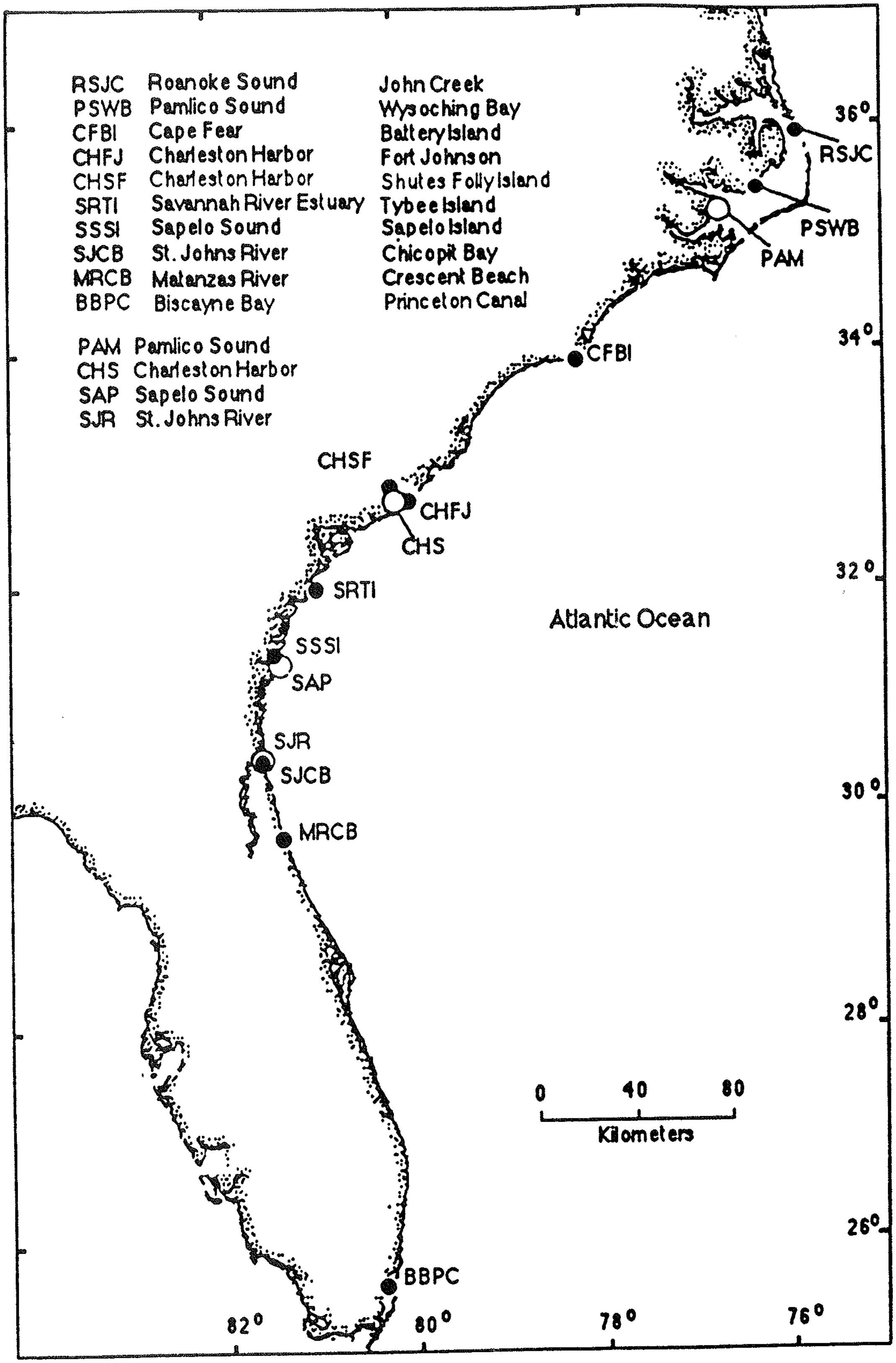

FIGURE 1. LOCATIONS AND NAMES OF NATIONAL STATUS AND TRENDS SITES ALONG THE SOUTHEASTERN ATLANTIC COAST.

TABLE 2. EAST COAST SITES THAT ARE AMONG THE MOST CONTAMINATED ON THE BASIS OF CONTAMINANT LEVELS IN BIVALVES AND FISH LIVERS. SITES ARE GROUPED IF THEY ARE LOCATED WITHIN APPROXIMATELY 20 KM OF ONE ANOTHER (NOAA, 1987)[a,b]

General Location	Site Code	Contaminant (ranking)
Casco Bay ME	CSC	Pb(1) Ag(3)
Salem Harbor MA	SAL	tChl(3) Cr(4)
Boston Harbor MA	BHDI	tChlP(6) tPAH (9) tPCB(12) Pb(6) Hg(5) Sn(7)
Boston Harbor MA	BHDB	tPAH(5) tPCB(8) Cr(15) Pb(4) Sn(6)
Boston Harbor MA	BHHB	tPAH(6) tPCB(14) Cr(12) Pb(5)
Boston Harbor MA	BOS	tChl(1) tPCB(2)
Buzzards Bay MA	BBAR	tChlP(7) tDDT(8) tPCB(1) Pb(15)
Buzzards Bay MA	BBRH	tPCB(10)
Buzzards Bay MA	BBGN	tPCB(9)
Long Island Snd CT	LIHR	Cr(2)
Long Island Snd NY	LITN	tChlP(10) tDDT(10) tPAH(7) tPCB(11) Pb(7) Sn(10)
Long Island Snd NY	LIMR	Pb(14) tChlP(15)
Hud/Rar Estuary NY	HRUB	tChlP(8) tDDT(12) tPAH (2) tPCB(4) Cd(5) Cr(1) Pb(3) Hg(2) Ni(9) Sn(1)
Hud/Rar Estuary NY	HRLB	tChlP(1) tDDT(1) tPAH(12) tPCB(2) Hg(10) Sn(3)
Hud/Rar Estuary NY	HRJB	tChlP(14) tDDT(15) tPAH(14) tPCB(15) Sn(15)
New York Bight NJ	NYSH	tChlP(4) tDDT(7) PCB(7) Pb(9) Sn(5)
New York Bight NJ	NYSR	tChlP(2) tPCB(3) Sn(12)
New York Bight NJ	NYLB	Sn(13)
Delaware Bay DE	DBBD	Cd(8) Ni(10) Ag(13)
Delaware Bay DE	DBKI	Cd (4) Ni(11) Ag(4)
Delaware Bay DE	DBFE	Ni(13) Ag(14)
Delaware Bay DE	DBAP	Cd(2) Ni(7)
Chesapeake Bay MD	CBMP	Cd(3) Ni(3) Ag(3) Sn(9)
Chesapeake Bay MD	CBHP	Ni(5) Ag(8)
Cape Fear NC	CFBI	As(1)
Charleston Harbor SC	CHFJ	As(4) Ag(15)
Charleston Harbor SC	CHSF	As(5) Sn(11)

a Criteria for inclusion of a Mussel Watch site on this list are that it displays: (1) three or more contaminant concentrations ranking in the upper15 concentrations, or (2) two concentrations ranking in the upper 10, or (3) at least one concentration ranking in the upper 5, or (4) that at least one contaminant concentration is in the upper 15 concentrations and the site is located within 20 km of a site meeting any of the prior three criteria for that contaminant. The criteria for inclusion of a Benthic Surveillance site on this list are that at least two mean concentrations rank in the upper five of 43 concentrations or that a single concentration ranks in the upper three.The rankings of concentration of these twelve chemicals have been used to compile this list: tChlP, tDDT, tPAH, tPCB, As, Cd, Cr, Pb, Hg, Ni, Ag, and Sn. Fish livers were not analyzed for tPAH.

b Three letter code designates a Benthic Surveillance site, four letter code designates a Mussel Watch site.

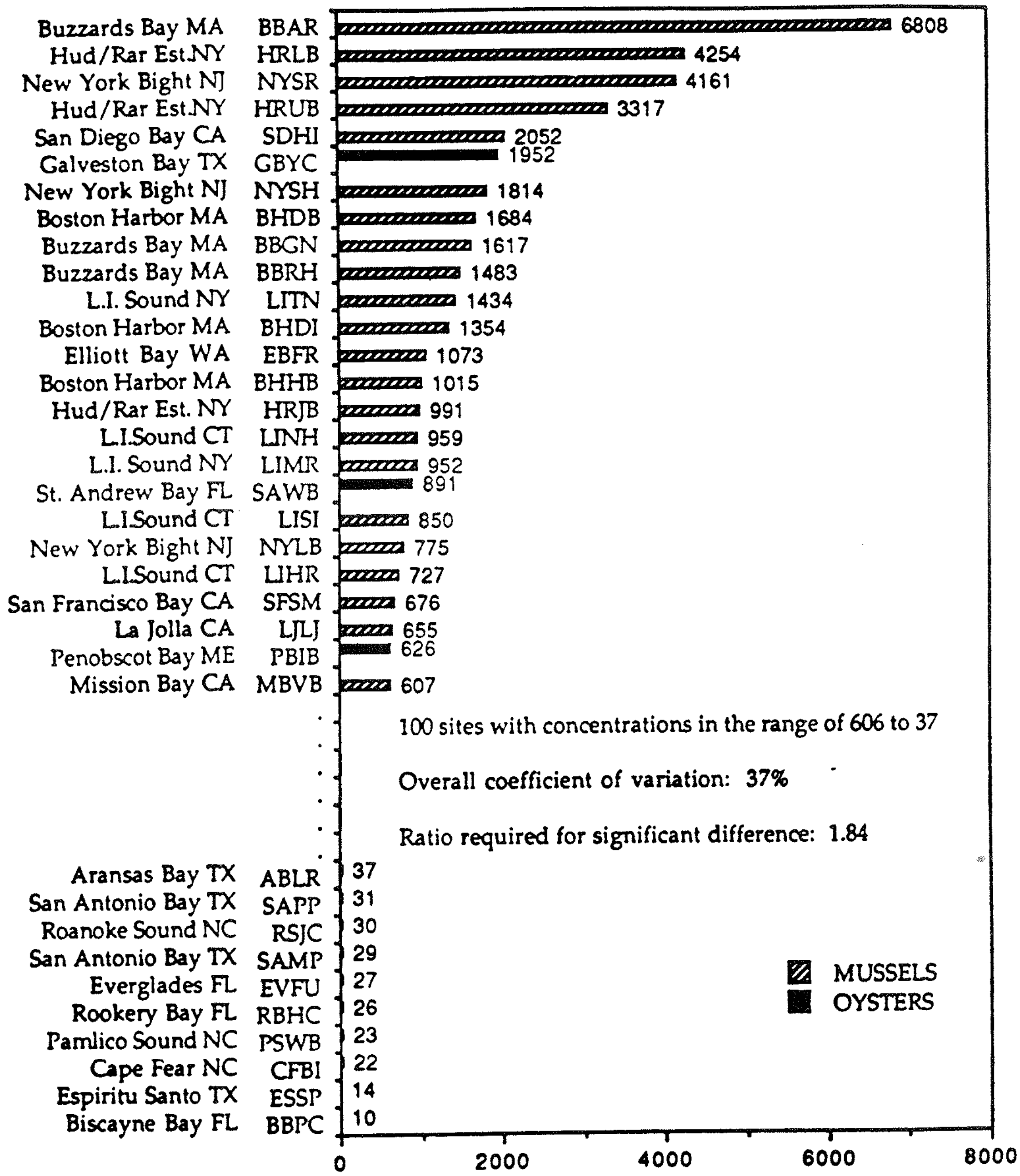

FIGURE 2. RANKINGS OF tPCB CONCENTRATIONS (ng/g-dry weight) IN BIVALVES (NOAA, 1987).

TABLE 3. SOUTHEASTERN SITES AND CONTAMINANTS WHOSE CONCENTRATIONS RANKED AMONG THE UPPER 25 OF 145 MUSSEL WATCH SITES AND THE FIRST 20 OF 43 BENTHIC SURVEILLANCE SITES

Mussel Watch Sites		Contaminant (ranking) upper 15	upper 25
Roanoke Sound	RSJC	------	------------
Pamlico Sound	PSWB	------	------------
Cape Fear	CFBI	As(1)	tPAH(24)
Charleston Harbor	CHFJ	As(3)	Ag(15), Sn(19)
Charleston Harbor	CHSF	As(4)	tPAH(19), Ag(22), Sn(11)
Savannah River	SRTI	As(7)	------------
Sapelo Island	SSSI	As(6)	------------
St. Johns River	SJCB	------	------------
Matanzas River	MRCB	------	------------
Biscayne Bay	BBPC	------	------------

No southeastern Mussel Watch sites sites among the upper 25 for any of these chemicals: tChlP, tDDT, tPCB, Cd, Cr,Pb, Hg, Ni

Benthic Surveillance Sites		Contaminant (ranking) upper 5	upper 20
Pamlico Sound	PAM	------	------------
Charleston Harbor	CHS	------	------------
Sapelo Island	SAP	------	------------
St. Johns River	STJ	------	tChlP(14)

No southeastern fish liver samples among the upper 25 for any of these chemicals: tDDT, tPCB, As, Cd, Cr,Pb, Hg, Ni,Ag sites. Three of these four sites are in Charleston Harbor or the St. Johns River which, on the basis of proximity to cities and industrialization, might be expected to be among the more contaminated southeastern sites. Even they, however, are not particularly contaminated when viewed from a national perspective.

Analysis of the corresponding sediment data has not yet been completed. Preliminary conclusions from Mussel Watch sites with fine-grained sediment are that the As concentrations at the Cape Fear and Charleston Harbor sites are relatively high on a national scale but that, as with bivalves, other contaminant concentrations in the southeast are not particularly high.

Reference

NOAA, 1987. National Status and Trends Program for Marine Environmental Quality. A Summary of Selected Data on Chemical Contaminants in Tissues Collected During 1984, 1985, and 1986. NOAA Technical Memorandum NOS OMA 38. NOAA Office of Oceanography and Marine Assessment, Rockville, MD.

THE PROGENY OF ESTUARIES

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Drifting in the waters that flow back and forth through the estuaries is a group of young or larval stages of many animals that utilize the area as a nursery ground. This group, called plankton, depends ultimately on the highly productive areas of marsh along the coasts for food and habitat (Duncan, 1975). As many planktonic animals grow and mature, they become significant components of commercial and recreational fisheries that have developed over the years.

The recruitment of new year classes and the commercial and recreational fisheries are extremely valuable components of the estuaries. In 1986, Americans consumed a record high of 14.7 pounds of seafood per person [National Marine Fisheries Service (NMFS), 1987a, 1987b]. While this figure may seem small, it represents a commercial industry of 239,000 people harvesting 6.0 billion pounds of seafood worth 2.8 billion dollars. Statistics for the recreational fishery are even greater with 17 million people harvesting over 460 million fish and spending 7.5 billion dollars. Estimates indicate that 90% of the commercial harvest of the southeastern quarter of the country and 70% of the recreational catch inhabit the estuaries for all or part of their life history (Mager and Thayer, 1986). The area of interest for the current symposium is the estuarine and coastal waters of North Carolina, South Carolina, Georgia, and Florida. Here, the commercial industry landed almost 250 million pounds of seafood worth over 150 million dollars in 1986 (Table 1). These figures represent one pound out of every 24 and one dollar out of every 17 of the catch landed by the entire U.S. fleet. Just for fun, Americans landed almost 60 million fish from the Southeast region representing one fish out of every eight landed recreationally in the entire country. Forty-one percent of the recreational catch came from waters of our estuaries and 40% from coastal waters off our beaches.

The most basic part of understanding these very valuable resources is knowing and naming the animals and plants--taxonomy. In the estuaries of the region, the taxonomy of most organisms is fairly well understood, particularly for the common species. However, there are some groups and some planktonic stages where study has only begun. This first step is necessary before the complex interrelationships and interdependencies can be understood.

Biological inventories have found a tremendous diversity of life inhabiting the barrier islands and estuaries. Studies of beach fronts indicated that between 250-300 species live in the sand

TABLE 1. TOTAL FISHERIES CATCH FOR 1986

	COMMERCIAL		RECREATIONAL
	Pounds	Dollars	Number Landed
United States	6,000,000,000	2,000,000,000	466,100 000
Southeast	248,600,000	154,700,000	58,835,000

TABLE 2. COMMERCIAL SHRIMP LANDINGS FOR 1975 - 1980

	Percent (%) of Total Catch by Weight for Each State		
States	Whites	Browns	Pinks
North Carolina	5.6	72.5	21.9
South Carolina	63.0	36.7	0.3
Georgia	79.7	20.1	0.2
Florida	78.4	18.2	3.4

and in the water, intertidally and subtidally (Knott et al., 1983; Delancey, 1984). Investigations on oyster beds found 89 different species of invertebrates occurring in the beds (Klemanowicz, 1985). Zingmark and others (1978) found over 12,000 different plants and animals inhabit the coastal plan. Comparatively few species were dominant components of the commercial and recreational catch; however, dollar value to the fisheries is not the only criterion for importance. For example, the spot was listed as the third most frequently landed recreational fish in the region (NMFS, 1987b). Workers at Skidaway Institute of Georgia found that, regardless of size, spot ate mainly small copepods that live on, in, and near the bottom sediments of our estuaries (Stickney et al., 1975). Hence, to understand changes in the population of spot, one should understand population changes of its copepod prey and factors influencing the distribution of copepods (i.e., dredging impact, etc.).

The most valuable marine harvest in the commercial fishery of the South Atlantic area is shrimp. There are three species--white, brown, and pink shrimp. In Florida, Georgia, and South Carolina, white shrimp are most numerous and valuable with browns second (Table 2). In North Carolina, browns are dominant with pinks second [South Atlantic Fisheries Management Council (SAFMC), 1981].

Much is known about the biology of shrimp although not all questions have been answered. Recently, workers have managed to open the extremely resistent sperm capsule of white shrimp and to even document this on videotape (Dougherty et al., 1987). This is a very important step toward experimental breeding programs of mariculture efforts. However, to illustrate the need for further study, the brown shrimp has been fished commercially for over 170 years, but its precise spawning grounds remain unknown.

There are primarily two seasons for catching white shrimp--spring, when the overwintering shrimp are large enough to move offshore and spawn, and fall, when shrimp spawned in the spring are large enough for harvesting. Factors in the estuaries have been found that enable workers to project the catch and then regulate the season to maximize both reproductive success and catch. Winter water temperatures below 47 degrees Farenheit for ten or more days have caused major kills which reduce the spring harvest (Whitaker, 1984). Factors useful in managing the fall season are the size of the spring catch, river discharge from June through August that hopefully is sufficent (15,000 cubic feet per second in Cooper River, SC) for the young grow under the preferred conditions of fresher waters, and sufficient discharge in the fall to drive the adults off into the fishing grounds (Whitaker, 1984). For browns, experimental trawling of juveniles in spring and early summer has been used as the main tool for predicting and regulating the season (Purvis and McCoy, 1974; Whitaker, 1984). Counts of the planktonic larvae of browns ingressing into the estuaries are currently being tested as an additional technique for forecasting catch (Whitaker, 1984). However, as our environment changes, the usefulness of these techniques will have to be re-evaluated.

Shrimp mariculture represents both a new industry and a competitor for use of estuarine areas, particularly impoundments. The mariculture industry in the U.S. in 1983 harvested over 260,000 pounds of freshwater shrimp worth 1.3 million dollars from 239 acres, most in Hawaii (Rhodes, 1984). In South Carolina in 1986, two big farms and several smaller ones harvested marine shrimp from 83 acres at a rate of 2,000 pounds per acre (Carolina Coasts, 1987a). Impoundments, initially built for rice culture, have been managed for water fowl by opening and closing flood gates at appropriate tides to maintain desired water levels. Attempts have been made to flood impounded areas at times when shrimp postlarvae are abundant, to supplement their diet, and to subsequently harvest the adults. This action has the effect, however, of eliminating these areas as nursery grounds for other important species (McGovern, 1986).

Blue crabs are the second most valuable estuarine species to the commercial industry in the area. In 1986, over 180 million pounds were harvested in the U.S. valued at 58 million dollars (NMFS, 1987). Harvest from the South Atlantic area accounts for almost 30% of the catch (Dressel et al., 1983). Current management techniques utilize a five-inch minimum size, the return of all egg bearing females, and the licensing of commercial crabbers and crab pots. Advances have been made in developing a soft shell industry which holds peelers until just after molting. A large scale soft shell industry operates in North Carolina and is currently being promoted in other states (Whitaker et al., 1987).

Oyster landings from estuaries of the South Atlantic are significantly less than 10% of the national harvest. The decline in oyster production has resulted from a loss of areas due to pollution, reduction in labor pool, and economics. Recent efforts in mariculture, mechanization of harvesting, and marketing indicate hope for future success (Burrell, 1982).

In addition to the commercial fishies, the recreational fishery is very important in the South Atlantic area. Among important recreational species is the red drum, also called the redfish, spottail bass, or channel bass. Red drum are the most sought-after fish in inshore waters of South Carolina (Low et al., 1986). In 1987, this fish was one of two given gamefish status by the South Carolina legislature, a legal classification prohibiting the sale, purchase, or transport of fish except, with proof, from states that allowed such harvesting. Size and catch limits were also established (Carolina Coast, 1987b).

Much research has been done on red drum. The rate of growth and age at size has been determined not only for the adults but also for the larvae (Peters and McMichael, 1987). The age structure of a population is important management information, with different techniques for managing fast and slow growing fish. Major shifts in age structure may indicate major stresses on the population. Most fish are aged by counting the rings laid down on the inner ear bones, called otoliths, similar to counting the rings on the trunk of a cut tree to determine its age. Even daily rings can be counted on the otoliths from larval fish to back-calculate the exact time of spawning which then can be used in management. The size and age at sexually maturity, or first spawning, is another important character and was used to set the minimal size of red drum at 14 inches in South Carolina during the summer spawning season, hopefully allowing each fish to spawn at least once before capture (Carolina Coast, 1987b). For better management, further research is needed, such as quantification of the effects of environmental factors, migration and movement analyses through tagging studies, and improved catch and effort statistics (Mercer, 1984).

The gag grouper is an important offshore fish accounting for almost 10% (83,500 pounds) of the recreational reeffish catch in the area and accounting for over one seventh ($400,000) of the total commercial finfish value in South Carolina in 1986 (NMFS, 1987b; unpublished data). Juveniles inhabit eelgrass and subtidal oyster beds of estuaries of the South Atlantic area. However, it was not until 1980 that the larvae were identified (Keener et al., in press). After searching through collections from throughout the entire South Atlantic Bight over ten years, most of the larvae were found in an area about 80 miles due east of Charleston, South Carolina. Spawning may be centered around the new or full moon in March. Using currents and probably swimming behavior, the larvae migrate into the estuaries 45 days after spawning. This ingress occurs in masses estimated as high as half a million per inlet (Stender et al., 1983). After feeding all summer in the grass and subtidal oyster beds, the juveniles migrate offshore in the fall. Still questions remain. What animals and plants are these juveniles depending on in the estuaries? How mobile are the juveniles? What are the factors cueing the ingress and egress? Can the increasing counts be used to forecast year-class strength of the adults eight years later when recruited into the fishery?

Numerous questions on recruitment and fisheries remain. We are learning an astounding volume of critical information. Complete bibliographies have been published on the more important species, such as the red drum, to assist in compiling information. Several further examples of the advances made over the last 30 years are noteworthy. Pioneering work in aging larval fish has been published within the last ten years (Haake et al., 1982). In fishery statistics, shrimp have been harvested and statistics recorded since 1817, but it was not until 1959 that landings were reported by species and it has only been since the 1970's that accuracy has been high and consistent (Whitaker, 1984). National recreational surveys were not begun by the National Marine Fisheries Service until 1979 (NMFS, 1987b).

There remains one final user of estuaries that deserves attention. Homo sapiens, man, the one species charged with the responsibility for all the others. We depend on our estuaries for commerce, recreation, and aesthetic satisfaction. The 239,000 fishermen are not the only ones whose livelihood depends on our estuaries. Within the region, there are three main ports - Wilmington, North Carolina, Savannah, Georgia, and Charleston, South Carolina. Charleston is currently the third most productive port facility on the eastern seaboard. About half the tonnage currently moved through the port has destinations or origins in Georgia or North Carolina. The South Carolina State Ports Authority announced in February the signing of a new contract with the Sealand Corporation that will increase tonnage handled from 600 thousand tons per year to 1.2 million tons per year. The news media indicated that the additional tonnage may move the port into the number two slot. The port currently has an economic impact in excess of one billion dollars and directly employees some 24,000 people. Twenty-nine percent of the state's agricultural products is exported through the port making the port critical to the state's farm workers (Pender and Wilder, 1974; Chesley, 1982). All of these are also offsprings of our estuaries.

The stresses on the estuaries of the South Atlantic area are many and are pressing. Some result from natural causes. In North Carolina, the occurrence of the red tide from October 1987, to February 1988, has affected both the natural habitat and man, with estimates of the North Carolina seafood and restaurant industry losing over 16 million dollars.

Many stresses are man-made. Earlier in this symposium, Congressman Thomas mentioned a few of the environmental concerns resulting from the increased dredging at the Kings Bay Naval Station. Just recently, several new items in South Carolina have highlighted the stresses on local estuaries. Some of these are:

Rediversion - In 1985 the majority of the flow from the Santee Lakes, approximately 18,000 cubic feet per second, was re-diverted from the Cooper River to the Santee River. Given a typical daily useage of 3000 cubic feet per three months per family of four (pers. common., Charleston Public Works, December 10, 1987), this volume of water per day is roughly equal to the total daily consumption by three-fourths of the population of the entire country. This major change in the environment is currently being studied by a host of state and Federal agencies. The impact of the resulting changes in recruitment and management techniques may provide the substance for a future symposium.

Habor Deepening - A contract was recently signed that will increase the depth of Charleston Harbor from 35 feet to 41 feet. In 1986, 10.5 million cubic yards of silt was dredged from this area to maintain the 35-foot depth, representing the volume of mud that could cover one acre of land 1.2 miles deep.

Erosion - Alternatives for legislative action were discussed at a recent conference at Folly Beach to combat the massive erosion there that has occurred since the construction of the jetties to Charleston Harbor (Shepard and Wanless, 1971).

Land Use - Projections indicate that by 1990, 75% of the U.S. population will live within 50 miles of the coast [National Ocean Service (NOS), 1985]. In the five years from 1981-1985. NMFS commented on 23,393 proposals to alter 184,187 acres of wetlands in the southeastern U.S., indicating intense pressure for development. Mitigation through habitat creation is one option in confronting this pressure; however, the effectiveness of habitat creation has yet to be evaluated (Mager and Thayer, 1986). Recently, the South Carolina Coastal Council proposed changes in guidelines to facilitate the development of one acre tracts of isolated, freshwater wetlands through an easier permitting process, while requiring the reconstruction or creation of twice that amount.

Community Interest - Recently, Charleston hosted the Southeastern Wildlife Exposition. The attendance by some 40,000 people indicates a tremendous interest in maintaining our resources.

The decisions that need to be made must continue to be intelligent ones based on as complete a data base as possible and as fast as possible. Hopefully, the information provided has conveyed some insight into the importance of estuaries and beaches to our marine resources and recruitment.

In conclusion, the following, written by St. Francis of Assisi about 1220, is most appropriate:

"O God, who hast made all the earth and every creature that dwells herein; help us, we pray thee, to treat with compassion the living creatures entrusted to our care, that they may not suffer from our neglect nor become the victims of any cruelty. Bless all who serve in their behalf and help us to find, in caring for them, a deeper understanding of this love for all creation; through Jesus Christ our Lord. Amen."

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GEORGIA'S NATIONAL ESTUARINE RESEARCH RESERVE

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Historical accounts of the past 200 to 300 years consistently praise the clarity of estuarine waters and the bountiful harvests of living resources which were available to the first settlers to arrive in these pristine environments. Many of these settlers had come from crowded and polluted cities boardering equally befoluled European estuaries and were anxious to partake of this bounty. However, as time passed it became increasingly apparent that these once beautiful and productive environments were losing their attractiveness, as well as their ability of sustain high biological yields.

Today, we know the problems which can beleaguer our estuaries: contaminanted waters resulting from industrial and municipal sources, loss of yield of living resources and in some cases replacement of sought-after species bu less desireable organisms. However, while we know the symptoms of the problems, we often do not know the way to treat the causes, nor do we have adequate knowledge of the critical processes which act to cleanse and refurbish an estuary.

Considerable resources are being spend in many areas to "clean-up" or "mitigate" the insults which have historically been imposed on these systems. Yet, without an adequate knowledge of the processes within the estuary, we are likely to miss important trends, while keying in on less sensitive indicators of the estuaries health. Many of these controlling processes are microbial or chemical in nature and can be overlooked if too much concern is spent on the stocks of fin fish or other commercial species. Our estuaries have been contaminanted by years of misuse and it is naive to think that 1- to 5-year programs will somehow return these systems to their past glories.

Estuarine management requires cooperation of scientists, managers and the public to maximize usage of the system without injuring it. To accomplish this feat, knowledge of how a healthy estuary functions is essential. The medical sciences could not be expected to treat the sick without knowledge of how a healthy human body functions. The science of environmental management should not be expected to do differently.

The need for long-term understanding of estuarine dynamics and function has been recognized and programs are being established to preserve for scientific study relatively pristine environments. One of these programs is the National Oceanic and Atmospheric Administration's (NOAA) National Estuarine Research Reserve System. "The mission of the System is to establish and manage, through a shared Federal-State cooperative effort, estuarine research reserves representative of biogeographical regions and estuarine types in the U.S. National Estuarine Research Reserves provide opportunities for long-term research, education, and interpretation. Scientific and educational programs are particularly focused on the development of information for improved coastal management decision-making" (Tweedt, 1987).

The marshes and portions of the upland drainage of the Duplin River on the western side Sapelo Island (Fig. 1) were designated as the second National Estuarine Sanctuary in 1976. With the reauthorization of the Coastal Zone Management Act (CZMA) in 1986, the designation of the Sanctuary was changed to Research Reserve to emphasize the role of research in these units. Thus, the Sapelo Island National Estuarine Research Reserve (SINERR), which represents the Carolinian Biogeographic Province, is one of twenty National Estuarine Research Reserves currently in the System.

The Carolinian Biogeographical Province extends from North Carolina to Florida and is characterized by extensive salt marshes and barrier islands. The SINERR encompasses approximately 3800 acres of salt marsh and 2100 acres of upland, which represent some of the last marshland sections on the East Coast to retain their natural condition. The SINERR is manaaged by the Georgia Department of Natural Resources' (DNR) Game and Fish Division. In addition, the University of Georgia's Marine Institute is located at the southern end of Sapelo Island, within the SINERR. At the time of the designation of the Sanctuary in 1976, the Marine Institute, which has been conducting basic research on salt marsh ecosystems since 1953, received a 50-year lease to allow it to continue its studies.

Currently, the Marine Institute has a permanent scientific staff and eight Ph.D.'s and a operating budget of approximately $1,500,000. The Marine Institute also hosts visiting scientists from across the Nation and around the world who wish to pursue valid scientific research themes in marsh and barrier island environments. During the 35 years of the Marine Institute's existence, over 600 papers have been published dealing with the scientific investigations conducted by resident and visiting scientists alike. Active areas of research include: primary and secondary production in the marsh and estuary, microbial ecology, nutrient dynamics, predator-prey interactions, population dynamics, and trace element and organic biogeochemistry. Much of the research conducted at the Marine Institute is undertaken within the SINERR.

In addition to the research conducted by the Marine Institute, the DNR conducts educational tours and monitoring activities.

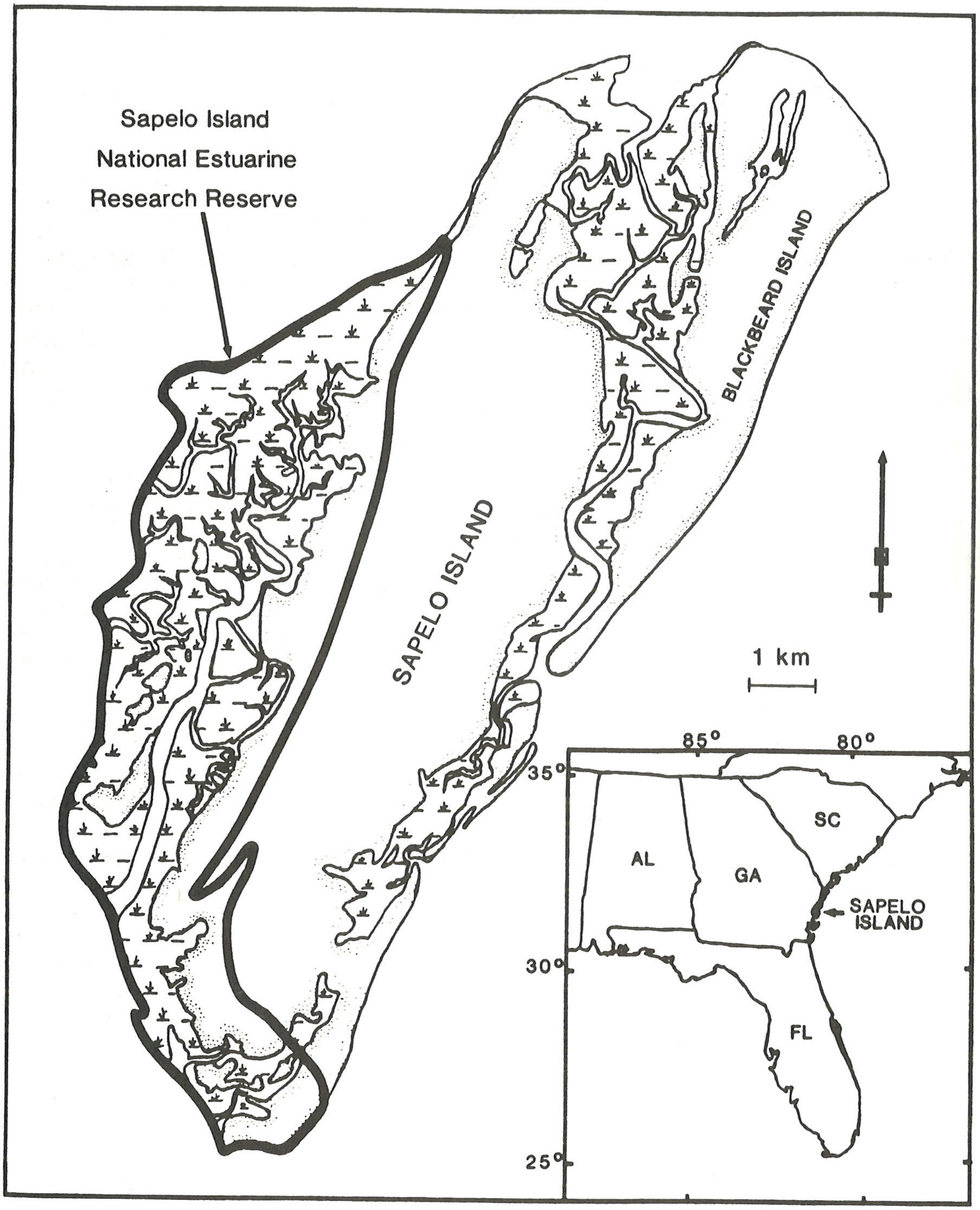

FIGURE 1. SAPELO ISLAND, GA SHOWING THE BOUNDARIES OF THE NATIONAL ESTUARINE RESERCH RESERVE (SINERR).

Thus, the concept of long-term investigations of relatively low-impact estuaries is being undertaken in the SINERR and the processes which control healthy marshes are being defined. However, there is still a great deal of effort needed. To truly reap the benefits of a program of this nature, National Estuarine Research Reserves must increase the interactions between sites within the System, and must attempt to reach out to other similar programs, such as the Long-Term Ecological Research Program of the National Science Foundation. Furthermore, more effort must be placed on developing significant interactions between the scientists and the managers of coastal environments and to bringing both groups together with the public in these areas. Only if there is a coupling of these divers groups, will the programs be successful and true "management" of our estuarine environments be achieved.

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LONG-TERM ECOLOGICAL RESEARCH ON THE NORTH INLET FOREST - WETLANDS - MARINE LANDSCAPE, GEORGETOWN, SC

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Introduction

Although it has been recognized for a long time that ecological phenomena vary on time scales ranging from seconds to thousands of years, for various reasons most studies of environmental systems dynamics have not only been restricted to a relatively short period of time (1-3 years) but also restricted to studying only one or a few processes at a time. Synoptic, comprehensive studies of a system are generally lacking. To address these and other shortcomings, the National Science Foundation established the Long-Term Ecological Research (LTER) Program in 1979. At present there are 15 sites in the LTER network, representing major habitat types ranging from the Rocky Mountains to the Atlantic Ocean and from Alaska to the south of the United States, making a coordinated network of sites, facilitates, and comparative experiments involving investigators from a number of distinct ecosystems. This allows analyses and testing of theoretical constructs relating to broader landscape questions that were not available before. Each site is considered a regional or national research facility and collaborative research with other investigators or institutions is encouraged.

The North Inlet Estuary was one of othe original six sites selected in 1979. Since then funding has enabled a continuous ecological study of this relatively pristine estuary. Before summarizing some of the results of our study, a brief overview of North Inlet system is presented.

North Inlet Estuarine Ecosystem

Estuaries are characterized by a connection to the sea through which sea water surges in and out on a tidal rhythm. In the Southeast the resultant intertidal zone is typically dominated by a single species of vascular plant, *Spartina alterniflora*. As characteristic of estuaries, a source of freshwater dilutes the oceanic sea water thereby reducing the salinity. Although estuaries vary in size, shape, and structure, they have these and other characteristics in common. The North Inlet System exhibits all of these characteristics and is an excellent example of an undisturbed southeastern estuary. It should be noted that the use of the term "undisturbed" and "pristine" to describe the North Inlet System does not imply that this area has not been frequented by humans. Relative to most other estuarine systems in the U.S., the North Inlet System has been subjected to little man-induced alteration. Most of the highlands surrounding this system are owned by two private foundations (the Belle W. Baruch Foundation and the Tom Yawkey Foundation) and these foundations have dedicated in perpetuity these highlands which are not developed for the study of barrier islands, marine systems, and forests.

North Inlet is located 110 km northeast of Charleston, SC and encompasses about a 3000 ha (Figure 1). A number of distinctive habitat types exist within the North Inlet Estuary. There are approximately 2,600 ha of marshland, chiefly dominated by Spartina alterniflora. Oyster beds and reefs are extensive; other intertidal zone habitats include open study beaches, protected sandy beaches, mud flats having varying admixtures of different-size sand-mud particles, dunes, marsh and forest habitats.

From a physical as well as a biological point of view the North Inlet Estuary is a dynamic environment. The semi-diurnal tide has a mean range of 1.6 m; however, during spring tides the tidal range has exceeded 2.2 m with associated maximum currents of $1.4 m \cdot s^{-1}$. The estuarine waters usually have salinities in the range from 30 to 34^{o}/oo, due to low freshwater runoff into the system. However, after frontal passages or summer rain-thunder storms, the salinity has been measured as low as 4^{o}/oo in the upper reaches of some creeks.

North Inlet is vertically homogeneous, with a weak horizontal salinity/sigma-t gradient from the inlet to Winyah Bay. The major variation in the above physical parameters is explained by fluctuations due to the tidal wave, thus North Inlet is a tidally-dominated estuary. North Inlet is classified as a type 1-a estuary in the Hansen-Rattray system. Many southeastern estuaries apparently fit this type which is an advantage in mathematical modeling of estuaries, as variations with respect to depth may be of minor importance, allowing for the use of vertically integrated hydrodynamic equations in any flow-simulation effort.

For intensive study of short-term and long-term ecological processes, the North Inlet System is ideal for a number of reasons. First, the boundaries of the estuary are well-defined. Second the estuary and marsh lands are relatively undisturbed. Its waters are classified as "highest quality" by the South Carolina Department of Health and Environmental Control. The estuary is sufficiently small to be studied, but large enough to have distinctive estuarine characteristics. The inlet is approximately 900 m wide. The distance from the inlet to the pier at Clambank is approximately 3000 m by boat. Third the marsh lands and estuary are sufficiently large to permit experimental manipulation and control of experimental areas, and extensive land holdings provide space for construction of experimental ponds. Extensive oyster beds, as well as large

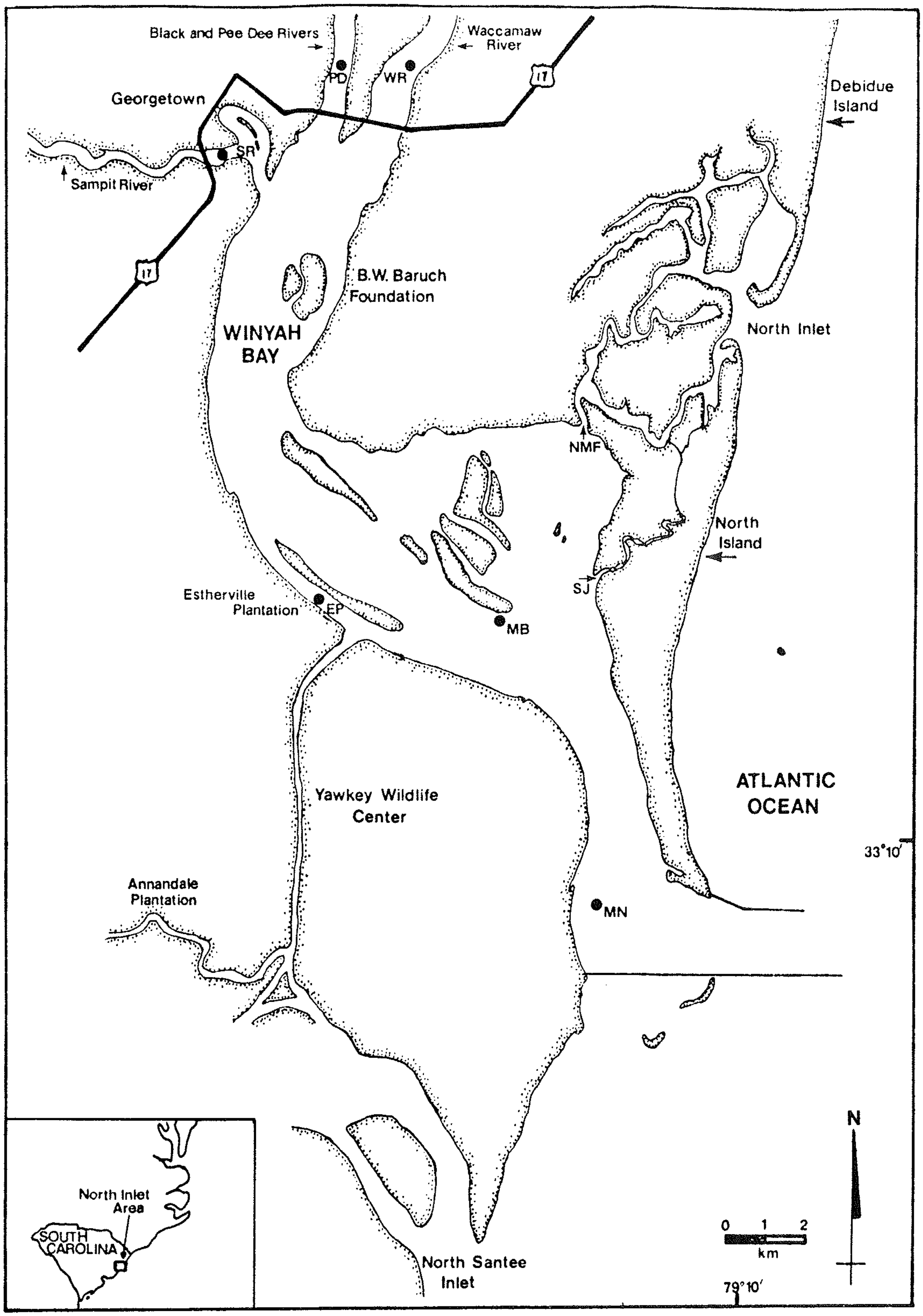

FIGURE 1. LOCATION OF THE NORTH INLET ESTUARINE SYSTEM NEAR GEORGETOWN, SC.

populations of other commercially important species, such as blue crab, shrimp and mullet, are found in this region. Fourth, study of the biota and physical parameters of the marshes and estuary has been in progress since January 1970. Although far from being a complete study, data from these earlier investigations furnish a realistic basis for future studies. Tide elevation, wind speed and direction, atmospheric pressure, and rainfall have been recorded continuously for more than 7 years. To make the biotic and abiotic data readily available to investigators, a well-developed data management system exists. Fifth, the flow exchange between the estuary and the Atlantic Ocean and Winyah Bay takes place in a few well-defined creeks which have been monitored. It is possible to determine inputs of water and nutrients from groundwater, terrestrial runoff, and rainfall. Sixth, most of adjacent wooded highlands and the marshes are owned and protected by the Belle W. Baruch Foundation. The University of South Carolina has a long-term contract with the Foundation to manage the marine area. This arrangement insures protection for long-term studies. Seventh, a staff of 70 associates has demonstrated not only its ability to study separate problems associated with coastal environments, but also its ability to work on complex problems in a coordinated interdisciplinary manner. The resident staff presently numbers 20. Eighth, laboratory, boat, and dormitory facilities are adjacent to the estuary, and finally, the North Inlet System is included as part of the Long-Term Ecological Research Program funded by the National Science Foundation.

Long-term Ecological Research

In response to a well documented need to study ecological phenomena on a long-term basis, the National Science Foundation has established a program on Long-Term Ecological Research. The National Science Foundation currently funds research at 15 LTER sites throughout the United States, many having an emphasis on wetlands. Some of these sites are in their second five-year cycle of funding. Although intersite diversity in research approaches exists, the following common core research questions are being addressed in relation to time and space as well as natural and induced stresses or disturbances:

1. Dynamic Patterns and Control of Primary Production

2. Dynamics of Selected Populations of Seed Plants, Saprophytic Organisms, Invertebrates, Fish, Birds, and Mammals

3. Patterns and Control of Organic Accumulation (Biomass) in Surface Layers and Substrate (or Sediment)

4. Patterns of Inorganic Contributions (Atmospheric or Hydrologic) and Movement Through Soils, Groundwater, Streams and Lakes

5. Patterns and Frequency of Apparent Site Interventions (Disturbances) Over Space and Time (Drought, Fire, Windthrow, Insects or Other Perturbations) that May Be a Product of, or Induce, Long-Term Trends.

Space restrictions do not permit a detailed discussion of the results of North Inlet LTER studies, but Table 1 lists the major ecosystem components being studied. The extensive long-term data base developed is available to investigators from other universitites, agencies and institutes who want to study a specific research project for a short-time, but whose results can be better interpreted within the context of a long-term data set. For example, is the short-term study being done during an unusually cold year? The following sections highlight some of our findings. A list of LTER papers, which currently numbers 90, has been prepared and is available for distribution.

A. Primary Production

1. Algal Production by R. G. Zingmark

Primary production is a useful concept to consider and an essential measurement to obtain when attempting to understand and model the complexities and dynamics of any ecosystem. The published literature generally states that such production in southeastern U.S. salt marsh estuaries is dominated by the marine vascular plant <u>Spartina</u> <u>alterniflora</u>. Over the past several years we have tested the hypothesis that the various algal communities together fix more carbon than does <u>Spartina</u>, by measuring the temporal and spatial variations of production by these algal communities. Our results are summarized as follows:

a. Phytoplankton

(1) Chlorophyll <u>a</u> correlates highly with carbon 14 uptake during all seasons and is thus an excellent predictor of phytoplankton productivity in North Inlet estuary.

(2) Reasonably accurate estimates of annual phytoplankton productivity can be modeled by considering the rate of photosynthesis as a function of light, the depth of the euphotic zone and the diurnal variations in solar irradiance during the year.

(3) Five years of daily sampling indicate diurnal and seasonal variations in phytoplankton biomass (chl <u>a</u>) that predict similar changes in productivity.

(4) Although phytoplankton productivity varies seasonally, the annual rate has remained similar from year to year.

(5) Depth integrated (areal) productivity was correlated

TABLE 1. LIST MAJOR ECOSYSTEM COMPONENTS

Primary Production

- *Spartina*
- Phytoplankton
- Microphytobenthos
- Epiphytes and Neuston

Microbiology

Population Dynamics

- Zooplankton
- Macrozooplankton
- Meiobenthos
- Macrobenthos
- Oyster Bed Community
- Fishes
- Birds

Chemical Processes

- Nutrient Dynamics
- Geochemistry

Physical Oceanography

Sedimentology

Modeling

Statistics

Data Management

primarily with light and temperature, rather than with nutrients and salinity. Thus we suspect that most of the time the production of phytoplankton is not nutrient limited.

b. Macroalgae (Seaweeds)

(1) Though macroalgal production has been largely considered as insignificant to the annual carbon budget in southeastern saltmarshes, that in North Inlet Estuary is at least twice that of the phytoplankton.

(2) Macroalgal productivity occurs largely in the winter in North Inlet, when other plant communities are seasonally dormant.

(3) 95% of macroalgal production is contributed by only 7 of the 51 species found in North Inlet.

c. Microphytobenthos (Microalgae Associated with the Sediments)

(1) The microphytobenthos is largely composed of benthic diatoms.

(2) Rates of productivity of this community is about equal to that of the macroalgae and twice that of the phytoplankton.

(3) There are not as pronounced seasonal variations in productivity as is seen in the previous two communities.

(4) There are severe methodological problems that limit a greater understanding of the dynamics of this community.

d. Epiphytic (Those Growing on Spartina) and Neustonic (Floating on the Surface) Algae

(1) Although ubiquitous in North Inlet Estuary, we do not have measurements of the productivity of these communities as yet. Our estimates of production are based on a few studies in the literature.

e. Summary Table: Average Rounded Estimates of Net Areal Primary Productivity of the Various Plant Communities in North Inlet Estuary (1980-86).

	Annual Net Production ($gC_{m}^{-2} \cdot year^{-1}$)	Percent of Net Production
Plant Community Spartina (Studies by Dame and Morris)	400	40
Macroalgae (Seaweeds)	200	20
Microphytobenthos (Mud Diatoms)	200	20
Phytoplankton	100	10
Epiphytes and Neuston	100	10
TOTALS	1,000	100%

Our bottom-line numbers support our hypothesis that the algae are collectively more important (60%) to primary production in North Inlet Estuary than is *Spartina* (40%).

2. *Spartina* Production

a. Studies by R. Dame

Because primary producers usually control the amount of energy and matter entering an ecosystem, it is crucial that this trophic level be accurately measured in order to understand the structure and function of a specific ecosystem. In the salt marsh ecosystems of the southeastern U.S. *Spartina alterniflora*, is often the dominant Emergent vascular plant. Spatial variability in aboveground *S. alterniflora* primary production is well known, but little is known of temporal (interannual) variation. In addition, belowground primary production has seldom been measured concurrently with aboveground production. Our initial study was designed to determine the primary production of *S. alterniflora* both spatially and temporally and to identify possible factors which cause year-to-year variability.

To date, we have been able to show that aboveground production is greater than belowground production along the creeks while the reverse is true in the high marsh. Our estimates of total *Spartina* primary production (4.8 to 6.7 $kg.m^{-2}yr^{-1}$) are similar to those determined for Georgia. When aboveground and belowground production are considered, *Spartina* converts about 2.2% of incident solar radiation into organic biomass. We were also able to show that aerial biomass and production were increased by wet (rainy) winters. Rainy winters in our area appear to be associated with the EL NINO - Southern Oscillation climatic event of the Pacific region.

Our recent work is directed towards the landscape level organization of coastal systems. Within our area, we defined by satellite imagery three distinct systems: salt water, salt marsh, and uplands. The spatial variation of the salt marsh is easily observed and quantified (patch area) with these remote sensing techniques, but temporal variation is difficult because of the few usable images available over the past 10-years. In addition, attempts to relate primary production to remotely sensed images have also been frustrated by the poor image histories available.

It is foreseeable that Spartina production as well as coastal landscapes could be monitored by remotely sensed images if (1) sufficient images were available with ground truthing and (2) if image analysis systems were more available to this scientist.

b. Sea Level Variability Affects Primary and Secondary Production in Estuaries by Jim Morris.

Temporal variability in local sea level has an important effect on primary production in salt marshes because of changes in the duration and frequency of flooding along elevational gradients in the intertidal zone. Sea level along the South Carolina coast oscillates seasonally with an amplitude of about 30 cm. The minimum occurs during winter and early spring and the maximum occurs during late summer and autumn. However, there is considerable interannual variability in the magnitude and timing of these sea level oscillations. Mean sea level during July and August, the height of the growing season, varies as much as 15 cm from year to year. At the location of this research in marshes near Georgetown, SC, a decrease in mean sea level of this magnitude decreases the frequency of flooding and the duration of flooding in the high intertidal zone (ca. 40 cm elevation) by approximately 50%. This is a partial explanation for the strong correlation between annual primary production in these marshes and the mean sea level during July and August. Annual primary production has been observed to vary by a factor of two.

Changes in flooding frequency and duration have profound effects on the chemistry of sediments in the intertidal zone. In particular, sediment salinity increases in the high intertidal zone to values significantly greater than sea water and is strongly affected by flooding fequency. The change in sediment salinity is one probable mechanism by which the productivity of Spartina alterniflora is regulated by flooding frequency.

Interannual variations in primary production or of sea level of the magnitude that we have observed could have important consequences for secondary production as well. For example, we have found a significant correlation (p less than 0.01) between the annual penaeid shrimp harvest from the East Coast during the past six decades and sea level during July and August (mean July-August sea level was detrended to remove the long-term annual rise). There was no significant correlation when time lags of 1 to 4 years were included in the regression model. This suggests that shrimp production may be responsive to sea level because of the effect that total marsh area flooded and duration of flooding may have on feeding time and predator avoidance. Because of these and other possible mechanisms, including nutrient regeneration and transport, there are numerous implications for biological processes in the coastal zone of sea level fluctuations.

B. Marine Plant-Microbial Interactions by Garriet W. Smith

Over the past six years, data have been collected from six estuaries relating to vascular plant-microbial influences on the origin, transformation and fate of nitrogen in diverse coastal marine environments. These measurements are being correlated to the existing marine vegetation, physiochemical characteristics of the environment and land use practices. This is being done in an attempt to discern natural patterns of marine plant distributions, their role in marine ecology and how this is affected by anthropogenic activities.

The estuaries being studied include: A Spartina dominated, fine-texture sediment estuary (North Inlet, SC); a Spartina - seagrass dominated, impacted to pristine tropical coastline (Kingston Harbor and the Hellshire coastline, Jamaica, West Indies); deep-water Halophila environment (St. Croix, USVI); an oligotrophic carbonate pristine estuary (San Salvador Bahamas); and a heavily impacted carbonate environment (Barbados, West Indies).

In general, data from these studies indicate the following:

(1) The presence of seagrasses have a profound influence on the distribution of other marine organisms in subtidal sediment. This is due, in part, to nitrogen enrichment (North Inlet, SC, and St. Croix studies).

(2) The distribution of tropical seagrass assemblages appears to be most strongly influenced by sediment composition, which in turn, has a significant effect on nitrogen fixation, (San Salvador, Jamaica, Barbados and St. Croix studies).

(3) Microbial transformations if nitrogen varies in importance (for plant nutrition) depending on the environment (all sites).

(4) Seagrass successional patterns are strongly influenced by ambient nitrogen or phosphorus concentrations, depending on the environment (all sites).

(5) Land use which results in increased sedimentation devastates established seagrass meadows more so than any other activitiy so far observed (Jamaica, Barbados).

C. Zooplankton Studies by S.E. Stancyk

Long-and short-term studies of zooplankton have been undertaken to elucidate the role this biological component plays in estuarine ecosystems, and the factors controlling species composition and abundance in the zooplankton community on various time and spatial scales. Ultimately, predictive models will allow interpretation of quantitative changes in the community, and additional analyses such as multdimensional scaling will elucidate quantitative relationships among co-occurring species that control the sequential and/or successional changes in populations through time. These predictive capabilities also will allow deviations from expected future ecosystem states to be quantified.

Long-Term Studies

Six years of biweekly sampling of zooplankton at one or two different stations have yielded important information on the temporal and spatial abundance of zooplankton species in North Inlet Estuary.

At the level of biweekly sampling, differences between stations in terms of total numbers, numbers of species or dominants were not significant. Although between-station differences might have occurred at intervals not easily characterized by biweekly sampling, the greatest differences occurred between sampling dates.

There is a repeatable pattern of occurrence for the dominant species in the ecosystem, including consistent seasonal changes in total zooplankton abundance as well as seasonal changes in the dominant forms. In particular, the zooplankton population increases in early June each year, remains relatively abundant until-September, then drops until the next June. Dominant species remain the same from year to year, and fewer than ten species make up over 80% of the organisms by number.

Rankings of some of the dominants have changes from year to year; in particular, barnacle nauplii became quite abundant in 1983 and 1984, and although total zooplankton numbers did not change appreciably, barnacle nauplii nearly equalled copepods as dominants in those years.

Among ecologically important subdominants such as benthic invertebrate larvae, patterns of regular (e.g., bivalve larvae) and irregular (e.g., polychaete larvae) occurrence were seen. Juveniles of these forms generally appear in the benthos shortly after their occurrence in the plankton, then disappear.

Short-term Studies

During two separate 48-hour periods, bihourly pump and net zooplankton samples have been taken simultaneously with fish and macrozooplankton samples. Pumps and nets capture different taxa with different efficiencies. Organisms in the plankton exhibit a variety of horizontal and vertical distribution patterns relative to tide and daylength which modified their susceptibility to transport and/or predation. Gut contents of 40-60mm anchovy (Anchoa mitchelli) reveal that they generally take large, abundant prey, unless smaller prey are extremely common. They also show an unexpected selectivity for some rarer forms, especially bivalve larvae.

D. Meiobenthos by B.C. Coull

The purposes of this phase of the LTER project are (1) to determine long-term population/community patterns of meiobenthic populations at two sites (one mud, one sand) and (2) determine factors controlling patterns. Some general results are:

(1) The meiobenthos has been sampled continuously since September 1972 (monthly through 1980; every two-weeks from 1981 - present). This is the longest continuous such data set in existence.

(2) There is no cycle greater than one year in abundance at either site. Some copepod species have a 6 month periodicity.

(3) Seasonality is different at the two sites. Maximum abundance is in Spring (March) in mud; Summer (July) in sand.

(a) Mud seasonality appears to be controlled by juvenile fish (spot) predation. This has been tested by field and mesocosm experiments.

(b) Sand seasonality appears to be climatically and physically controlled.

(4) Juvenile spot (20-50 mm) feed on meibenthos exclusively. Feed preferentially in muddy substratum.

(5) Sand sit fauna is chaging as Debidue Island progrades to south and site becomes muddier. Original community is present in similar hydrographic regime to what sand site was orginally.

(6) Using two techniques, (radioactive tracers and stable isotopes), we found that meiofauna feed primarily on detritus and bacteria in situ. From the radioactive tracer work, the resident meiofauna appears to keep bacteria in a log growth phase - bacterial turnover times of 31 hours are required to replace the population lost to meiofaunal grazing.

(7) Meiofauna are regularly suspended into the water column. This is a function of shear stress on the bottom and most significant at peak ebb and flood tides. In contrast to the dogma that they are entirely sedentary, 1-5% of the meiofauna is in suspension during flowing tides.

(8) Several predictive models on long-term trends have been completed.

(9) The long-term data set has served as a baseline data to ask testable hypotheses. The experiments conducted to answer certain questions (seasonal control, resuspension, etc.) have been generated from the long-term data set.

E. Macrobenthos Substudy by F. Feller

Our primary objective is to first describe and quantify temporal changes in the natural sub-tidal benthic community, then to ascertain which processes may cause major, directed, shifts in community structure (e.g., relative abundance of species, alterations in the times at which various taxa dominate, or the degree to which sampling variance or population biomass deviates from expected levels), and finally to predict future states of the benthos in North Inlet.

We have seven complete years of samples collected (n = 173 dates), at two sites of which 148 are processed. The first five years of data have been analyzed (1981-1985). We take eight replicate core samples every 2 weeks at the Bread and Butter mud-bottom station. The Debidue sand-bottom station was dropped in 1984.

Debidue: Sampling error [variability between replicate cores (n=2) within a given date] was consistently higher than that between dates, hence it was very difficult to identify statistically significant trends of any taxon through time. the fauna were most abundant in the spring following a winter low. The community was dominated by polychaetes, bivalves, and amphipods. Despite the low signal-to-noise ratio, nearly all taxa showed an increased in abundance from 1981 to 1984.

Bread and Butter: This community was dominated by polychaetes and oligochaetes, with bivalves a lesser component. Fauna are most abundant in winter, with a low in the summer. Abundances (10^4 per M^2) are typical for this type of habitat. Seasonality was consistent each year, with year-to-year differences in abundance most obvious.

Short-term laboratory mesocosm studies using killifish and penaeid shrimps as predators have failed to show a strong linkage with macrofaunal prey. We are now isolating smaller subunits of the intertidal creeks to perform predator exclusion experiments designed to detect the impact of fishes and macroinvertebrates on the benthos. Empirical measurements of benthic biomass are nearing completion for data analysis.

F. Macrozooplankton, Motile Epibenthos, and Nekton Studies by Dennis M. Allen

The purpose of my LTER supported research has been to document and interpret the temporal dynamics of macrozooplankton (1-20 mm.) motile epibenthos, and nekton with respect to the "nursery" function of salt marsh habitats. Little information is available on mechanisms and factors influencing larval dispersal and recruitment in southeastern estuaries. We have sampled zooplankton, fish, and shrimp populations every 2 weeks for 7 years to examine inter-annual variations in abundance, biomass, and life stage composition and their relationships to fluctuations in other ecosystem components. Based on preliminary data analysis, some of the results of this work are summarized as follows:

(1) There are distinct patterns of change in taxonomic and/or life stage composition within the zooplankton and nekton during the year, such that the summer fauna, which has higher species diversity and total abundance/biomass, is very different that the winter fauna.

(2) The timing and duration of the period of occurrence of most taxa are usually well defined and predictable. For example, recruitment patterns for all major taxa of larval fishes were almost identical during each of the first 4 years.

(3) Patterns of abundance are not as regular as patterns of occurrence. Large fluctuations in densities of most macrozoplankton, juveniles fishes, shrimps, and crabs within their periods of occurrence were not related to fluctuations in measured environmental parameters in any consistent manner.

(4) Interannual variations in the abundance of larval fishes which recruit from ocean spawning areas were strongly correlated to salinity patterns. Low salinities during wet winters enhanced recruitment of spot, Atlantic croaker, and pinfish to otherwise high salinity tidal creek habitats. Relatively small interannual variations of summer larval fish abundance were attributed to stable environmental conditions among years.

(5) Early life stages of most fishes and crustaceans were most abundant in tidal creeks with complex epibenthic habitats than in higher energy sand habitats near the inlet, regardless of the origin of the larvae or time or year.

(6) Short-term macrozooplankton studies have demonstrated that first stage Zoeae of grass shrimp (*Palaemonetes spp.*) are hatched on nocturnal high tides and exported to the ocean where intermediate stages are passed. Megalopse (post stage seven) return to adult habitats in the marsh. Larval dispersal patterns for other taxa reflect adult distribution and reproductive behavior.

(7) Intensive short-term sampling effects indicated tidal and diel periodicity in the abundance of most macrozooplankton constituents. Changes are related to both passive (tidal transport) and active (behavioral) movemements, and there are important implications of sampling design.

(8) Simultaneous collections of macrozooplankton and planktivorous fishes over 48 hour periods indicated selectivity by the fishes for certan dietary items. Predation by the bay anchovy, one of the most abundant fishes in southeastern estuaries, probably has a major impact on larval crustacean populations and macrozooplankton community structure.

(9) Settlement patterns of American oyster spat on vertical arrays of plates during a 5-year study (biweekly collections) indicated identical patterns of settlement throughout the estuary. The timing and duration of the period was closely related to water temperature and photoperiod, but variations in abundance within and among years could not be explained by fluctuations in environmental factors or availability of planktonic larvae. Although settlement in subtidal areas was high on clean surfaces, sedimentation and biological competition appear to prohibit the development of subtidal beds in the southeast.

G. Summary of Avian Processing Research by Keith Bildstein

Although birds are one of the more conspicuous components of the salt-marsh biomass, their role in estuarine ecosystems is little studied. In 1979 we began a series of studies aimed at assessing the patterns of avian distribution and abundance and species-specific energy flow on the North Inlet Estuary in an attempt to determine the ecological role of birds in this ecosystem. Our initial studies indicated that although 95 species of birds used the estuary throughout the year, two species, the Clapper Rail (*Rallus longirostris*) and the White Ibis (*Eudocimus albus*), were responsible for one-half of the avian induced energy flow. As a result of these finds, we focused our efforts on the White Ibis, using it as a representative abundant avian consumer, and have since concentrated our efforts on studies of (1) the factors affecting the distribution and abundance of ibises on the marsh and (2) the role of ibises in estuarine nutrient processing.

The majority of the White Ibis population at the North Inlet Estuary overwinters in Florida and the Caribbean, returning to coastal South Carolina in late March. Egg laying begins in early April. Our studies indicate that the number of ibises breeding in a large colony on Pumpkinseed Island in Winyah, Bay, directly south of the North Inlet Estuary, fluctuates as a function of the amount of rainfal in the 6-month period preceding the onset of egg laying. An examination of the feeding habitats of ibises breeding on Pumpkinseed Island revealed that parental ibises, although they sometimes feed on fiddler crab (Uca spp.) in nearby salt marshes, often fly inland to feed on crayfishes in fresh-water bottomland forest.

Following the fledging of young ibises in early June, however, large numbers of parental and recently fledged ibises shift from inland feeding sites to feeding on fiddler crabs in the North Inlet Estuary. Laboratory experiments with hand-reared ibises reveal that nestling ibises are capable of normal growth and development only when they are fed on low salt (i.e., crayfish) diets. Thus the availability of freshwater prey some distance from the salt marsh colony site apparently limits the numbers of ibises breeding in coastal South Carolina, and hence their impact on nutrient processing.

Because ibises are feeding in large numbers off the North Inlet Estuary in spring and early summer, but raising young in the estuary, they import considerable amounts of nutrients to the coastal ecosystem. Currently, we are assessing the importance of ibises as biotic vectors of nutrients (i.e., N, P, K, Ca) by comparing the amount of these nutrients being imported by breeding ibises with that imported to the system as a result of rainfall. Our studies reveal that, in spring, ibises contribute significant amounts of several nutrients to the ecosystem, at the very time that increased primary productivity in the estuary is reducing nutrient availability. These results suggest that coastal ecosystems associated with large colonies of breeding birds may have significantly different nutrient regimes than those lacking such colonies.

H. Nutrients by Elizabeth Blood

1. Daily Water Sample Studies. Daily water samples have been collected and analyzed since 1980. Some general trends have been noted.

Particulate fractions of carbon, nitrogen, and phosphorus change primarily in response to short-term episodic phenomena such as rain at low tide, wind-induced resuspension, and intrusions from Winyah Bay. Total nitrogen, phosphorus, and carbon dynamics are dominated by factors controlling the organic nutrient components. The timing and quantity of upland runoff and phytoplankton and *Spartina* biomass dynamics contribute to the seasonal patterns observed in total and organic nutrient dynamics. Inorganic nutrient patterns are less distinct varying with all the above mentioned periods or controlling factors.

Inter-Annual Variation - Daily Water Sample

Mean salinity (average of 6 years) is 32 ppt. On an annual basis (mean for each year) there is no significant variation in salinity. However, on a seasonal basis there are significant differences between years. In 1983 and 1984 the lowest monthly salinities were 19.4 and 22.3 while in 1981 and 1986 the lowest monthly salinities were 32.8 and 31.5, respectively.

Three general patterns were observed in inter-annual variation: a directional change wit time (decreasing over the 6-year period), inverse relationship with inter-annual salinity, and direct relationship with upland runoff.

On an annual basis, total phosphorus and nitrogen, particulate nitrogen and phosphorus were inversely related to the annual salinity variation (indicating transport of nutrients to the marsh with lower salinity waters). Dissolved organic nitrogen and phosphorus, sediments and particulate organic carbon concentrations have steadily decreased over the 6 year period. Prior to the drought of 1986, dissolved organic carbon concentrations in North Inlet were a direct function of runoff from backwater streams.

The high air temperatures and low rainfall during 1986 influenced certain nutrient and carbon fractions in North Inlet. The 1986 drought effect on the North Inlet system included an extended period of the highest water temperatures thus far recorded and the highest annual concentrations of nitrate/nitrite and dissolved organic carbon measured. Seasonal patterns in dissolved organic carbon, nitrate/nitrite and ortho-phosphate were distinctly different during 1986 than other years sampled.

Forest-Marsh Interactions

For the past 3 years we have been analyzing surface water drainage from a 53 ha watershed adjacent to Oyster Landing. Storm event samples have been analyzed for a variety of ions and nutrients. The objectives of the study are: (1) determine hydrographic nutrient changes, (2) assess the effects of salt water intrusion on stream chemistry under a variety of flow conditions, and (3) determine the flux of nutrients to the marsh. Highlights of the finds include:

(1) With flow initiation three concentration peaks are observed, initial peak as stream bed is wetted, +/-2 hours of peak of hydrograph and 6 to 20 hours after hydrographic peak.

(2) Nutrient and ion changes with stream flow are controlled by accumulation of ions in stream bed, source water contributing to the flow (ground water, saturated riparian zone, discontinous wetland areas) and dilution processes.

(3) Tidal water becomes enriched with nutrients as it returns to the marsh when tidal intrusions occur during "no-flow" periods.

(4) There is a rhythmic change in nitrogen species, chloride and sulfate consistent with tidal frequency when multiple tidal intrusions occur during low flow conditions.

(5) Tidal intrusions affect only the early portions of large discharge storms. The large upland runoff dominates the remainder of the nutrient dynamics over the hydrograph.

I. Preliminary Summary of Long-term Spartina Mineral Nutrition by H. Ornes

The working hypothesis of this substudy is that the nutrient status of *Spartina* could be responsible for occurrence of tall or short growth forms. Tall and short growth forms of *Spartina* from North Inlet, SC, were sampled monthly and divided into live and dead stems and roots before being chemically analyzed for 13 inorganic nutrient elements over the period of 1981 through 1985. Chemical analyses were completed in 1987 and statistical analyses are in progress.

Correlations and regressions are being calculated among nutrients and the growth parameters stem lengths, biomass, and number of stems per square meter. Rainfall, salinity, and soil water chemistry are also being considered.

Seasonal Nutrient Patterns: Live stems from tall and short *Spartina* showed significant seasonal changes in concentrations of N, P, K, Ca, Mg, S, Fe, and Al. These data document the normal uptake and distribution of nutrients during dormant and growth seasons.

Tall vs. Short Spartina Nutrients: Preliminary conclusions implicate several macronutrients and micronutrients as possible contributors to the occurrence of tall or short growth forms of *Spartina* at North Inlet, SC, Tall *Spartina* had significantly greater concentration of N in roots, P in stems and roots, K in roots, Mn in roots, and Fe in roots. These nutrients may partially account for the occurrence of the tall growth form. Short *Spartina* had significantly greater concentrations of S in stems and roots, Zn in stems, Cu in stems and roots, and P in roots. These elements may partially account for the occurrence of the short form.

J. Sediments by L.R. Gardner

(1) Suspended sediment levels are determined in the daily water sampled. The purpose is to understand factors and processes that govern concentrations of suspended sediment in salt marsh creeks in the hope of identifying the source and mode of depositon of fine-grained sediment in marshes. Lead-210 profiles indicated that marsh is accumulating sediment at a rate of about 2.0 $mm.yr^{-1}$ in balance with historic sea level rise. Bioturbation by fiddler crab causes rapid sediment turnover on creekbanks giving anomalous lead-210 profiles.

Major patterns of suspended sediment concentration in an annual cycle directly correlated with water temperature. This suggests that bioturbation is a major factor governing turbidity of these waters. Fresh water runoff events have only a minor effect on turbidity obscuring the role of major rivers in supplying sediment to the marsh. We plan to study effects of tidal flow on turbidity and the net transport of suspended sediment in order to resolve the dilemma posed by available net transport studies; i.e. marshes seen to export sediment instead of import as required by sea level rise.

(2) Sediment Chemistry. The purpose is to identify and understand spatial and temporal patterns of variation in the sulfur and carbon chemistry of marsh sediments and interstitial water. Clear temporal patterns do not seem to exist. The following spatial patterns have been identified along transects from creek bank to high marsh: increases in organic carbon, reduced sulfur, dissolved sulfide, sulfate depletion and pyritization index; decreases in pH, Eh, dissolved iron, acid volatile sulfur and fiddler crab burrowing. These patterns are thought to result from the complex interaction of spatial gradients in belowground production, sediment oxidation, pore water drainage and bioturbation.

<u>K. Upland Hydrology by Tom Williams</u>

Upland hydrology studies seek to determine factors controlling the movement of freshwater from the upland forests into the upper reaches of the tidal creeks. Data are collected on rainfall, surface runoff, and ground water on a series of forested watersheds surrounding North Inlet marsh. Hydrologic data are used in conjunction with studies of nutrient cycling to estimate nutrient input and transformation along the marsh forest boundary.

Forest hydrology along the southeastern coast is greatly influenced by the abundant rainfall and relatively high rate of evapotranspiration. Rainfall is distributed relatively uniformly throughout the year with an average of about 2.5 cm/week. While rainfall is relatively uniform, evaporation is highly seasonal with pan evaporation ranging from less than 1 cm/week in December and January to 6 cm/week in July.

Soils are young uniform marine sands on topography that is dominated by former marine geomorphic processes. The general land slopes toward the marsh with a slope of 2 meters/kilometer. Most forest watersheds are bounded by low lying former beach ridges. Within watersheds slopes are gentle seldom exceeding 5 m/km and surface drainage systems are poorly developed.

Water tables are very high and fluctuate widely due to the changing balance of rainfall and evapotranspiration. In late March water tables are generally highest and least variable.

Depths are often less than 30 cm and standard deviations are as little as 3 cm. During October or November water tables are lowest but also most variable. Average depths are over 1 meter with standard deviations 50 to 60 cm. Fall water table depths are dependent on presence or absence of tropical storms.

Flow in the streams entering North Inlet from the uplands is derived primarily from rain falling on saturated soil in some portion of the watershed. Unless the water table is at the surface, rainfall readily infiltrates into the sandy soils of the forest. Runoff occurs primarily from January to July. Upland runoff only occurs in the fall of years with tropical storms.

Future research will concentrate on predicting runoff based on topographic features of individual watersheds. Present data suggests that storm flow is generated by a definable source area. On experimental watersheds, it should be possible to use new GIS technology to define the physical boundaries of the source area based on rainfall rates and antecedent water table positions.

L. Ecosystem Studies

1. Summary of Ecosystem Research by Fred Sklar

The goals of the ecosystems research component of LTER are: (1) holistic analysis and integration of all data, and (2) conceptualization and development of community, ecosystem, and landscape level computer models. We have begun to summarize our large climatological, hydrologic, and water and sediment nutrient chemistry databases so that long term trends, disturbances, and seasonalities of all physical variables can be compared (statistically and empirically) with the North Inlet biotic databases. Physical variables are also being incorporated into large scale water budget models, process based ecosystem models, and spectral density models (i.e. time-series and periodicity analysis).

Data manipulations and compilations have also been completed on: (1) available DHEC water quality data, (2) discharge monitoring reports from each wastewater facility along the Waccamaw River, (3) USGS water discharge estimates for the Waccamaw and Pee Dee Rivers, (4) meteorological data from eight Baruch weather stations and three NOAA stations dating back to 1950, and (5) 1973 LUDA land cover data. Water quality stations in the Waccamaw River Estuary revealed significant spatial differences for dissolved oxygen, pH, salinity, nitrate-nitrites, and turbidity. Temporal variations were significant for temperature, salinity, dissolved oxygen, turbidity, nitrate-nitrites, and pH. These data and the North Inlet data are being combined to develop a Coastal Ecosystem Landscape

Spatial Simulation (CELSS) model, and are now in a form that accomplishes three things: (1) they provide us with the necessary forcing functions (i.e., input variables) and initial conditions to drive a CELSS model, (2) they indicate the seasonality of processes to be simulated, and (3) they give us a database for analysis and parameter estimation.

A CELSS model is being designed in modular units. Modular units are composed of either algorithms for a particular habitat type or sets of input/output commands. Work on the input/output modules that control processes between cells has not yet begun however, work on the habitat modules that control processes within cells is 50% complete. Habitat models that are complete or near completion include: freshwater marsh, wastewater treatment facilities, open water/river systems and forested wetlands. Habitat models still under development include: upland pine forest, salt marsh, residential, and agroecosystems.

The benefits of our ecosystem and landscape level analysis are far from realization because we have just begun this line of research and because we require additional support to: (1) purchase new areal images, (2) document land use changes, (3) digitize historical development of primary and secondary highways, (4) database ecological variables for further parameter estimations, (5) complete all habitat modules in a CELSS model, and (6) piece all modules together into a landscape simulation program. It is anticipated that the final output from our ecosystems research will help; (1) the South Carolina Coastal Council as they review coastal building permits, (2) the Waccamaw Regional Planning Office as they evaluate long-term land use plans, and (3) the DHEC of South Carolina as they calculate waste load allocations and non-point sources of pollution along the South Carolina coast.

(2) Studies by H. McKellar and D. Childers

The major objectives of the modeling component were to simulate seasonal variability of nitrogen and carbon fractions in the tidal creeks as a function of dynamic interactions among landscape components. Using a core model of tidal creeks nutrient/carbon dynamics, temporal interactions between the tidal creeks and the intertidal vegetated salt marsh, intertidal oyster reefs, subtidal benthos, the forested uplands were simulated. Nutrient exchange per unit surface area of these landscape components were derived directly from field studies in the Bly Creek sub-basin of the salt marsh estuary. The model was used to extrapolate these site-specific results to the broader landscape dimension by integrating the spatial distribution of each component (including areal coverage and elevation contours) and the corresponding temporal changes in the degree of surface water coupling between components via tidal inundation and runoff.

The model demonstrated several direct and indirect consequences of landscape component interactions in controlling the observed seasonal patterns of nutrient and carbon dynamics in the estuarine water. The simulated coupling between the intertidal oyster reefs and the tidal creek water column demonstrated the importance of this interaction as a control on nitrogen concentrations in the tidal creek water with secondary effects on nitrogen limitation and productivity of estuarine phytoplankton. Upland runoff of dissolved organic matter was also indicated as the major control of the seasonal dynamics of tidal creek DOC.

The model incorporates much of the perceived complexity of coastal landscapes with variable driving forces from upland and oceanic sources as well as detailed interactions among benthic, intertidal, and pelagic components. As an effective tool for budget integrations, the model was used to indicate consistencies and discrepancies in our present understanding of component exchanges and the culminating effects on total system outwelling.

M. Data Management by William Michener

Long-term research represents a major investment in personnel time, funding, and other institutional resources. Recognizing the value of the data sets generated under the auspices of LTER, Baruch Institute has made a firm commitment to development and maintain a flexible and powerful data management system. Special emphasis has been placed on data archival and documentation. The Baruch Data Management System may be classified into four primary components: data entry, quality assurance, analysis and archival.

Data entry includes both direct data acquisiton devices and manual entry techniques. The North Inlet climate monitoring station and most chemical laboratory instruments are directly interfaced to microcomputers for electronic data acquisition. Forms-driven full screen entry programs are primarily used for entering biological data (i.e., species abundance, morphometric data, etc.). Each computerized data entry screen mimics all or part of a raw data sheet, thereby facilitating the data entry process.

Quality assurance procedures include the incorporation of range-checks into software, printed reports for verification, and routine exploratory graphics and statistics for identification of outliers. All remotely acquired data (i.e. meterological data) are verified daily and instrumentation calibration and maintenance are regularly performed.

The long-term research program has benefitted from the close working relationship between investigators, data management personnel, and statisticians. Exploratory graphical and statistical procedures provide rapid feedback of results to investigators. Nested analysis of variance and autocorrelation analyses are frequently performed to examine variability in the data and have been useful in restructuring sampling protocols.

Data are stored in standard ASCII 80-column flat file format. A variety of backup media are utilized including printed report, tape, and mass storage devices. Data and programs are frequently exchanged with other universities via the BITNET network. Data documentation is an integral part of the data management systems. The documentation protocols have been established to provide secondary users with all information necessary to fully understand experimental design, methodology, data structures, data accessibility, and other relevant descriptors.

Data management personnel facilitate the research of visiting scientists by providing a variety of services including consultation, meteorological summaries, and intersite data exchange. A computerized bibliographic database is maintained to familiarize scientists with published papers resulting from research in North Inlet. In addition, the first in a series of data intensive technical reports (describing the LTER five-year seine and trawl study) is near completion. These technical reports will be valuable to visiting scientists in planning sampling programs.

Conclusions and Recommendations

A brief overview of the North Inlet LTER program has been presented. Based on the existence of a long-term database, information is available to investigators and/or institutions which could be useful for scientific understanding and for management decision-making.

There is need for comparative studies on which the responses of various estuaries, ranging from small to large systems and from the polar to tropical areas, are examined for similarities and differences. This need is especially acute in the Southeast where all the indicators point to unprecedented growth around the relatively small sized and understudied estuaries. How do these systems function and how are they responding to current anthropogenic stress? Management based on results of research (hopefully in the near future) should provide the basis for controlling growth-associated activities before these estuarine-wetland systems are degraded. It is economically and ecologically good sense to prevent environmental deterioration rather than attempt to reclaim and restore habitats.

There is a long-standing and continuing need to improve communications between management and/or regulatory personnel and research investigators. By improving discourse, the research scientist will have a better sense of relevant needs of managers and, in turn, managers will have an increased awarenes of scientific shortfalls. The continuing budget reduction in support of environmental interests at the state and Federal level makes it even more imperative that greater cooperation takes place which will result in a sharper focus on establishing priorities and reducing duplication of efforts.

THE UPLAND/ESTUARY/NEARSHORE COUPLE

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INTRODUCTION

For several decades now it has been generally recognized that tidal salt water marshes are indispensable to the vitality and productivity of commercially important coastal fisheries. Among other states, Rhode Island, in acknowledging the recognized link between salt marshes and the nurture of finfish and shellfish in the Narragansett Bay area, passed legislation aimed at preserving the ecology and commercial value of intertidal salt marshes.

Establishing the scientific basis of the connection between intertidal salt marshes and coastal fisheries has proved to be difficult, however. At the present time, the general consensus is that salt marsh/estuarine habitats are important with respect to fishery production because they serve as "feeding" and/or "nursery" grounds for the commercially valuable fishery species. Unfortunately, the very terms, "feeding" and "nursery", are nebulous. "Feeding" is generally related to the observation that estuaries are extremely productive of plant material which is supposedly available to fish and which constitutes the base of high fishery production. "Nursery" on the other hand generally pertains to the supposed physical and biological protection afforded young larval, juvenile and adolescent stages of fishery species while they reside in the estuary. A lack of basic information exists to rigorously evaluate the significance of the "feeding" and "nursery" hypotheses.

The National Oceanic and Atmospheric Administration, aware of both the intense pressures to "reclaim" or commecially develop, marsh "wastelands" and the importance of estuaries in supporting commercial fisheries has recently initiated a Program Development Plan for conducting the fundamental research necessary to provide the knowledge for effective management. One of the broad management problems identified by NOAA as needing research effort is the nature of ecosystem coupling and productivity in estuaries, which includes the question of enery/food pathways leading to fishery production in coastal regions.

In this paper I will briefly review some of the roots of the hypothesis that it is the abundance of food available to fishery species in estuaries that renders estuaries so productive. I will discuss the research that has been conducted to evaluate the hypothesis and indicate where additional research must be focused.

Origins of the Estuarine Feeding Ground Concept

In the lush marshes at Sapelo Island, Georgia, a group of scientists initiated during the 1950's some of the first measurements of metabolic processes in salt marsh-dominated estuaries. They made three observations from which was drawn a conclusion concerning the nature of estuarine productivity and linkages between marshes, bays and the ocean: (1) productivity of the marsh grass was comparable to the most heavily subsidized agricultural crops and a couple of magnitudes higher than the open ocean, (2) little of the plant material appeared to accumulate in the sediments, and (3) relatively little was degraded or consumed by higher trophic levels on the marsh. They concluded the considerable amounts of plant material were exported or flushed to adjacent creeks and bays by tides which bathe the marshes twice daily (Teal, 1962). At the same time that the Sapelo studies were underway, Burkholder (1956), Burkholder and Bornside (1957), and Darnell (1958, 1961, 1962) were conducting basic studies on the process of microbial decomposition of marsh grass and on the importance of the decomposing material (detritus) in supporting the trophic web of estuaries. Darnell (1967) concluded that organic detritus represented a major storage, transport and buffer mechanism in the estuarine ecosystem. It was generally thought at the time that most detritus was of marsh plant origin, that the most successful macrofauna in the estuaries were detritus feeders (i.e., had detritus in their guts), that microbes were indispensable in rendering the detritus available to macrofauna and that the microbial step was efficient enough to largely support the trophic structure leading to commercially valuable fish.

In 1968 Odum (1968) integrated these early observations on estuarine productivity and detritus and presented the "outwelling" concept in which it was presumed that net primary productivity of marsh macrophyte-dominated estuaries greatly exceeded local degradation and storage of carbon, and that the excess organic material was exported to the adjacent ocean where it was finally degraded and incorporated into an offshore detrital food web.

Although consistent with the evidence, the outwelling hypothesis was based on limited information. Nixon (1980) rigorously reviewed the research and literature upon which the concept was based and stated that although "outwelling was a quantitative proposition...there were virtually no quantitative data (in 1968) to support it." Nixon concluded on the basis of the most recently conducted research however, that there often did appear to be an export of organic matter from marshes, that the export contributed substantially to open water production in adjacent bays, but that there was no greater production of fish in areas with export than in coastal areas without marsh supplements.

The idea of organic export between salt marshes and estuaries has been one of the prevailing research themes in estuarine ecology during the past 20 years. Evolution of the idea has progressed substantially in ongoing research at Sapelo Island and elsewhere.

<u>Recent Progress Toward Understanding Outwelling In Coastal Georgia</u>

Two major approaches have been taken to examine the extent to which organic carbon fixed in marshes is exported to adjacent bay and nearshore systems: the direct flux and the mass balance approaches (see review by Hopkinson, 1988). With the direct flux approach, export is measured directly while with the mass balance approach, export is calculated as the difference between measured inputs of organic matter (e.g., plant production) and measured losses (e.g., animal respiration). Mass balance carbon budgets for the marsh/estuarine region indicate an overwhelmingly autotrophic nature for this portion of the coastal system, i.e., more organic carbon is produced than is stored and degraded. On the marsh, primary production exceeded sedimentation and respiration by a factor of 2.6 Creeks, rivers and sounds were distinctly heterotrophic, however, indicating great importance of organic matter inputs from outside the system. Incorporation of a direct measure of hydrologic export (Imberger et al., 1983) into a salt marsh model, enabled Wiegert et al. (1981) to estimate tidal export from the Duplin river marsh watershed at Sapelo Island to be 586 g C m^{-2} yr^{-1}. Further mass balance work of Hopkinson and Hoffman (1984) indicated that 361 g C $m^{-2}yr^{-1}$ was not accounted for in the model which was not deposited or degraded within the marsh/estuary; it was presumed that this amount must also be exported (Table 1).

A major weakness and potential cause of error in the mass balance approach in estimating organic export from marshes is that by definition, any material unaccounted for is considered to be exchanged (i.e. exported) with the adjacent system. Unmeasured or poorly measured metabolic fluxes or rates of burial are interpreted, perhaps erringly, as export.

In response to the weakness of the mass balance approach when applied to the donor system (i.e., the system which supplies the organic matter which is exported, in this case the marsh), Hopkinson and Kinsey at the Marine Institute on Sapelo Island approached the question of organic export by applying the mass balance approach to the recipient, or nearshore system. The rationale was that if organic matter was exported from the estuary to the nearshore, it should be possible to see a stimulatory effect of the organic matter on the level of community metabolism in the nearshore region. Hopkinson (1985) and Hopkinson and Hoffman (1984) showed that increased water clarity relative to the estuary, inputs of new nutrients and high rates of nutrient regeneration in the nearshore region did

TABLE 1. ANNUAL CARBON BUDGET FOR THE SAPELO ISLAND MARSH ESTUARINE REGION

PROCESS	FLUX ($g\ C \cdot m^{-2} \cdot yr^{-1}$)
Primary Production	326[a]
Aquatic* (gross)	2025[bc]
Marsh** (net)	
Community Respiration	
Aquatic*	520[d]
Marsh (excluding living macrophytes)***	738[e]
Sedimentation or Storage***	29[f]
Export***	+586[f]
Export and Balance***	+947

[a]E. Sherr, U. Georgia Marine Institute, Sapelo Island, GA.

[b]Includes phytoplankton production when marsh is flooded (E. Sherr, personal communication).

[c]Aerial production and relative area of creekbank versus high marsh (Gallagher et al. 1980); belowground production twice aerial production (Hopkinson and Schubauer 1984); factor of 0.45 to convert dry mass to carbon.

[d]Intertidal mudflat (Teal and Kanwisher 1961); planktonic respiration $0.64\ g\ C \cdot m^{-2} \cdot d^{-1}$ (Ragotzkie 1959).

[e]CH_4 (King and Wiebe 1978); CO_2 flux from bare mud (J. Hall and R. Christian, East Carolina Univ., Greenville, NC, personal communication); insects (Pomerey and Wiegert 1981); standing dead (<u>Spartina alterniflora</u> (Gallagher and Pfeiffer 1977); denitrification (Sherr 1977). Macrophyte respiration excluded because comparison is made with macrophyte net production which also excludes respiration.

[f]Pomeroy and Wiegert (1981).

*Units - $g\ C \cdot m^{-2}$ aquatic area $\cdot\ yr^{-1}$ (21% of total).
**Units - $g\ C \cdot m^{-2}$ marsh $\cdot\ yr^{-1}$ (79% of total).
***Units - $g\ C \cdot m^{-2}$ marsh and aquatic area $\cdot\ yr^{-1}$

From Hopkinson and Hoffman, 1984

indeed lead to enhanced levels of primary productivity and community metabolism offshore. They determined that the nearshore system required an input of 210 g C m^{-2} yr^{-1} in addition to local primary production to sustain the high rate of community respiration (Table 2). It was only during late spring and mid-fall that the nearshore region produced enough organic material to support measured levels of organic consumption. The annual ratio of primary production to community respiration averaged 0.72 in the nearshore region, which clearly indicated that the nearshore was dependent on allochthonous carbon inputs from either terrigenous or marsh/estuarine sources, or both.

A Holistic Coastal Interface Approach to Understanding Outwelling

Hopkinson and Hoffman (1984) spatially expanded the classical concept of the "estuarine region" into a more encompassing coastal interface system (Figure 1) which included not only the marsh and estuary proper but also the shallow-water (< 15 m deep) portion of the continental shelf seaward of the barrier islands. Explicit in this conceptualization are the linkages between the marsh and the estuary, between the marsh/estuarine complex and the nearshore region and the exchanges across system boundaries. The boundaries of this expanded "estuarine region" are the nearshore-mid/outer continental shelf boundary and the terrestrial-estuarine boundary which is dissected by rivers. The coastal interface system thus represents a physical expansion of the estuary as defined by Pritchard (1967) to include all shallow-water regions in which the water is measurably diluted by freshwater from terrestrial runoff, not just those areas which are semi-enclosed.

Although the concept of an all encompassing, integrated coastal interface system is simple, it is an important concept because it explicitly portrays the cause and effect linkages or couplings between specific portions (subsystems) of the whole system. The marsh is not a separate entity that functons in isolation from the bodies of water that surround it. Rather, processes that impact upon or influence the functioning of the marsh, indirectly affect the adjacent water bodies, which may in turn, affect the nearshore portion of the ocean also. An understanding of the effects of pollution in estuarine systems can only be complete when it is recognized that these systems are complex mosaics of many interrelated and integrated subsystems. Thus the integrity of the marsh ecosystem is determined not only by what happens in the marsh itself, but also by what happens in its upstream riverine watershed and in the adjacent offshore zone. Therefore, management of the estuarine zone depends to a considerable extent on management of the whole coastal interface system from river source to the ocean.

An understanding of estuarine productivity and outwelling must include an understanding of the forces and conditions that

TABLE 2. CARBON BUDGET FOR THE ESTUARINE PLUME REGION OF THE NEARSHORE GEORGIA BIGHT

PROCESS	FLUX (G c · M^{-2} · yr^{-1})
Primary Production [a]	539
Pelagic (gross)	
Community Respiration	
Pelagic	409
Benthic	340
Sedimentation	0
Balance	-210

[a]High turbidity causes light penetration to be insufficient for support of benthic primary production.

From Hopkinson and Hoffman, 1984

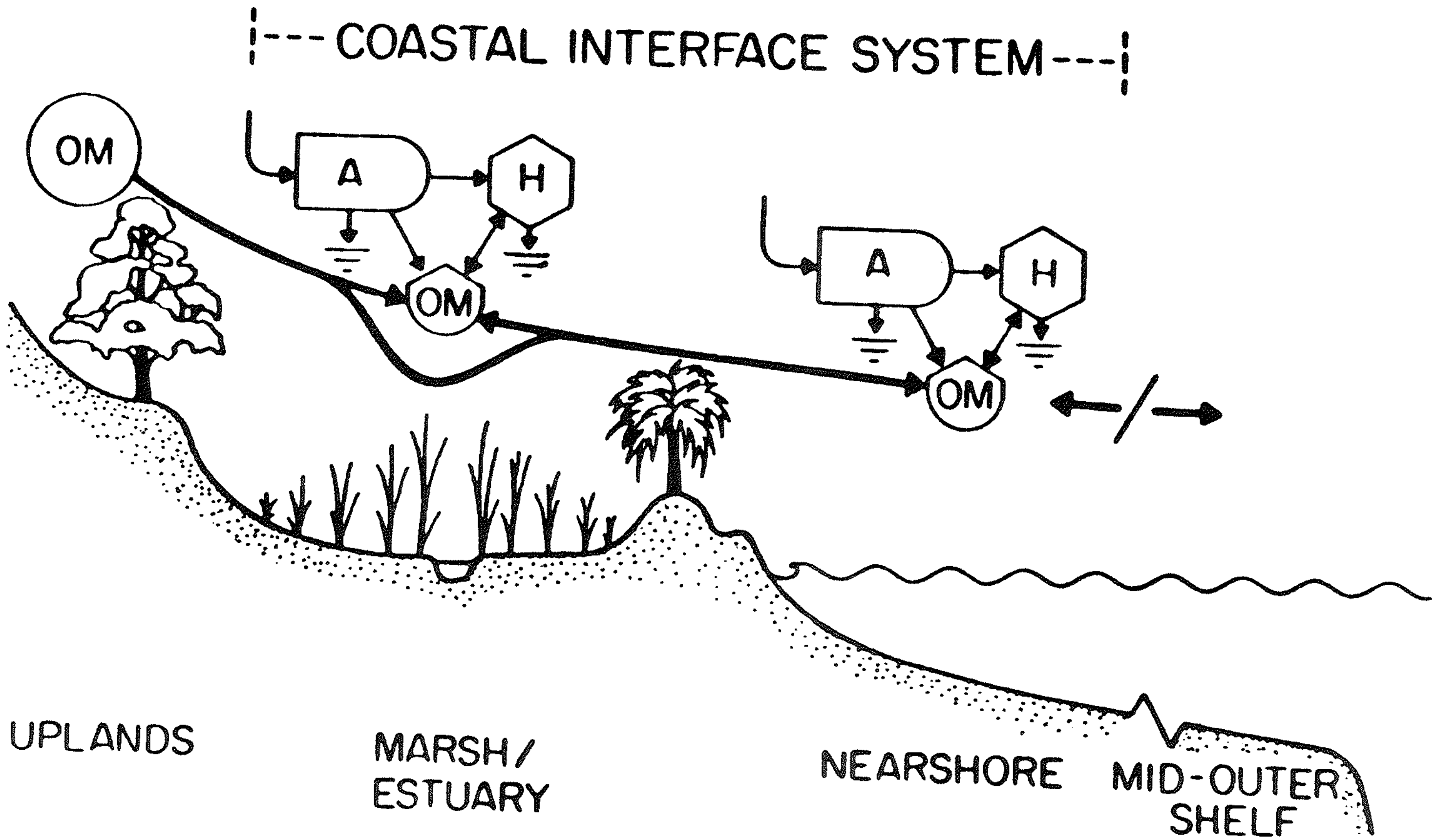

FIGURE 1. COASTAL INTERFACE SYSTEM (HOPKINSON AND HOFFMAN, 1984).

control these processes. The relationships between inorganic nutrient inputs, gross productivity and net ecosystem productivity constitute a basic concept that to date has received little attention in estuarine research.

The ecosystem production equation (Woodwell and Whittaker, 1968) shows the relationship between gross and net production:

$$NP + N_{ex} = GP - (R_a + R_h)$$

where GP is gross primary production, R_a is respiration of autotrophs, R_h is respiration of heterotrophs, N_{ex} is net exchange across system boundaries and NP is the annual increment in total biomass plus the annual build-up of organic carbon in the soil. NEP, net ecosystem production, is the sum of N_{ex} and NP. In systems without any NEP, gross production is in balance with community respiration, $(R_a + R_h)$ and the nutrients required for primary production are provided by local degradation of organic matter and recycling of nutrients from the organic matter.

As Smith (1984) recently illustrated, positive net ecosystem production is possible only when there is a positive net nutrient input unless the system is running on past storages and is in essence "running down". In this light, if we are to understand the process of net ecosystem production in the salt marsh/estuarine zone, we must also understand the relationship between cross boundary fluxes of nutrients to the estuary and estuarine productivity. NP and N_{ex} can only be positive (export) when GP exceeds R_a+R_h (assuming the system is not running down on past stores). GP can only exceed R_a+R_h when there is a net input of inorganic nutrient from outside the system. When there are no external inputs of nutrients, GP is coupled to R_a+R_h, and they are of equal magnitude. Coral reefs are examples of systems with balanced rates of gross production and community respiration. There is little net ecosystem production in a coral reef even though rates of gross production and community respiration are extremely high, because there are not external inputs of inorganic nutrients. An agricultural crop, on the other hand has substantial net ecosystem production realized in the form of crop harvest. Such production is totally attributable to high levels of external inputs of nutrients (fertilizer).

The primary source of nutrients to the coastal interface system is riverine inputs from the watershed. Thus it is important to recognize that changes in nutrient loading from the watershed can change the productivity and hence function of the coastal interface system. There is little information available to determine ahead of time whether such potential changes could be beneficial or detrimental to coastal fisheries production.

Current Estuarine Research Interests

There are a great number of ecosystem-level questions that are of current interest to estuarine scientists. With respect to the concept of the coastal interface system and organic carbon export from marshes to the ocean these questions can be divided into two categories: (1) What is the fate of the apparent excess organic carbon that is produced on the marsh? and (2) What are the ultimate sources of carbon which sustain the high levels of community respiration in the nearshore region?

The first question addresses the apparent paradoxes that currently exist in our models of marsh/estuarine carbon flow. For example, current evidence shows that (a) organic carbon is transported downstream from upper tidal creeks to lower sound; (b) more organic matter is consumed in estuarine water bodies than is produced there; (c) more carbon is transported from water to the marsh than is transported from the marsh to the water; (d) more carbon is produced on the marsh than can be accounted for by all directly measured losses (e.g., burial, consumption, export). Thus we can not determine the source of the organic matter in water bodies that is degraded, exported downstream, and deposited onto the marsh. Nor can we determine what happens to the unaccounted for carbon that is produced on the marsh.

There are three processes potentially contributing to the imbalance of our current organic matter budgets that are presently under investigation:

(1) Migrant consumers (fish, crabs, shrimp etc.) that move onto the marsh to feed and retreat to the water at low tide. The transfer of organic matter from the marsh to the water via the guts of these organisms could be substantial.

(2) Creekbank slumping is a common phenomenon that results in the transfer of an unknown quantity of organic matter from marsh to water.

(3) Spatial differentiation in carbon accumulation and loss in the marsh. Most studies have been conducted in geologically "mature" marshes (see Frey and Basan, 1978) which have limited exchange with adjacent water bodies. "Younger" areas of the marsh may be major sites from which organic matter is exported.

The second question concerns the external sources of the organic matter which is consumed offshore. As illustrated in our conceptual figure of the coastal interface system, organic matter may be introduced to the nearshore region from both the marsh/estuary itself or from rivers. In a research program currently funded by Sea Grant, the author is using the characteristic phenols, that are produced upon oxidation of organic samples containing lignin, as tracers for detecting the presence of riverine vs. estuarine components in offshore organic matter.

Conclusions

It should be obvious that due to the high degree of coupling between individual subsystems within the coastal zone (river inputs, marshes, bays, creeks, sounds, nearshore continental shelf, etc.) that wise management must take a holistic approach in recognition of the potential direct and indirect effects of activities in any particular subsystem on overall system function.

Numerous organic matter exchanges between all the subsystems of the larger coastal interface system have been demonstrated. It is also clear that organic matter is transferred from or through the marsh/estuary to the nearshore region. However, we still lack information concerning the trophic significance of outwelled organic matter. Does this organic matter become incorporated into an offshore food web which leads to commercially valuable fishes or is the organic matter respired away as CO_2 by inefficient micro-organisms? Is offshore primary production enhanced by nutrient release following outwelled organic matter decomposition by microbes? Or does degradation of the low quality (high C/N) organic material exported from marshes lead to a competition between micro-organisms and phytoplankton for inorganic nutrients with a resultant lowering of primary productivity in the nearshore region? These and other questions need to be resolved before we can truly appreciate the importance of salt marsh estuaries in coastal fisheries production.

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EPA'S REGULATORY ROLE IN THE COASTAL/MARINE AREA

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EPA Region IV has one-third of the contigous U.S. coastline, and in the last two years we have reorganized to giver greater priority to that coastline. In so doing the Region is striving to accomplish the following goals.:

- o Eliminate all man-induced wetlands and submerged aquatic vegetation losses. Establish programs for the restoration and creation of critical aquatic habitats.
- o Implement stormwater runoff controls and other applicable nonpoint source Best Management Practices in developed areas.
- o Reduce nutrient inputs sufficiently to maintain algal populations at a natural level.
- o Eliminate all point source discharges that are toxic to living marine resources.
- o Allow no new ocean outfalls.
- o Eliminate additional shellfish bed closures and strive to reopen existing closed areas.
- o Provide funding for cleanup of contaminated sediments and develop methodologies for decontamination and recycling.
- o Determine priority areas for establishment of estuarine sanctuaries and establish protection for same.
- o Establish strict policy regarding illegal ocean dumping.

The Region is striving to attain these goals through both regulatory and management programs. Perhaps the most significant regulatory role in the coastal area is the permitting program, both for Section 404 and the National Pollutant Discharge Elimination System (NPDES) Permits.

The Region has review authority for all COE 404 permits in wetlands and has the following responsibilities in the program:

- o Develop guidelines with COE for regulation of dredge and fill operations in wetlands.
- o Review permit applications and provide comments to permitting authority.

- o Make jurisdictional calls when necessary.
- o Approve and oversee State 404 programs.
- o Enforce violations under Section 309.
- o Prohibit any defined area's specification as a discharge site, or restrict its use by following procedures given in Section 404(c) whenever certain unacceptable adverse environmental effects would be caused by discharges.
- o Supply technical assistance to COE, other Federal or State agencies or local governments concerning water quality (WQ) issues, fish and wildlife resources and aquatic ecosystem structure and function

The basic precepts for implementing our review responsibility are the following:

- o Dredged or fill material should not be discharged into the aquatic ecosystem unless it can be demonstrated that the discharge will not have an adverse impact either individually or in combination with known and/or probable impacts of other activities affecting the ecosystem.
- o No discharge shall be permitted if there is a practicable alternative which would have less adverse impact on the aquatic ecosystem.
- o Where the activity associated with a discharge does not require access or proximity to a special aquatic site to fulfill its basic function (i.e., is not water dependent) practicable alternatives are presumed to be available unless clearly demonstrated otherwise.

No discharge of dredged or fill material shall be permitted if it:

1. Causes or contributes to violation of any applicable state WQ standard.
2. Violates any toxic effluent standard.
3. Jeopardizes the continued existence of an endangered or threatened species.
4. Violates requirements to protect a marine sanctuary.
5. Causes or contributes to significant degradation to waters of the U.S. Significant degradations include adverse effects on life stages of aquatic organisms and other water dependent wildlife, ecosystem diversity, productivity and stability, recreational, aesthetic and economic values.

EPA has certain enforcement authority under Sections 404 and 309 which it exercises when violation of these precepts occur.

The Region also administers the Ocean Disposal Program. The Region has allowed no 301(h) waivers of secondary treatment for marine discharges and allows no discharge of industrial waters. The Region does have twenty-nine sites which it will designate as ocean disposal sites for disposal of dredged material. In conjunction with the COE and the states the Regions designates the sites through a rule-making process and manages and monitors the site during and after disposal operations.

The Region's management programs in the coastal environment include the National Estuary Program, the Near Coastal Waters Initiative and the Nonpoint Source Program.

The National Estuary Program was established by Congress in the Clean Water Act Amendments of 1987, Sections 317 and 320. Procedures for nomination to, funding of, and objectives for the Program were included in the Act. The Act also named 12 estuaries for priority consideration. Management conferences are to be established for each designated estuary which will include representatives from the Federal, state, and local governments and the private sector. The Conference will then develop a Comprehensive Conservation and Management Plan over a 5-year period and provide for a means of implementing that plan. This program is authorized for funding for $12M/year for five years.

The Agency's Near Coastal Waters (NCW) Initiative is designed to:

o Focus existing EPA regulatory and management tools on the Nation's NCWs.

o Improve the science.

o Improve NCW information and data decision-making.

o Explore innovative approaches and solutions

o Institutionalize approaches and solutions.

o Communicate and educate.

o Present data in format amenable to assessing environmental qulity of estuaries.

o Transfer to states for verification and refinement.

o Make a case to Congress that estuaries are degraded or threatened by man's activities.

The Region has two pilot efforts underway in this Program, one in Perdido Bay and one for the entire Gulf of Mexico.

The Agency's Nonpoint Source (NPS) Program was enhanced by Section 319 of the Clean Water Act Amendments of 1987, Section 319:

- o Focuses on importance of controlling NPS.
- o Provides new direction and authorizes Federal financial assistance for implementation of state NPS programs.
- o Represents a shift in focus from technology based controls to water quality based controls.
- o Places more emphasis on state roles.

State assessment reports describing the nature extent, and effects of the NPS pollution and management programs which demonstrate how the states intend to accomplish control strategies are required by August 4, 1988.

Through coordinated efforts of Federal, state, local government entities and the private sector, the Region plans to follow a consensus-building process to implement these management problems. The management and research communities need an improved system of communication with each other. Fortunately, in the area of today's concern, (coastal Georgia and South Carolina) we are ahead of the developmental curve. With the exception of population centers (Grand Strand, Georgetown, Charleston, Hilton Head, Savannah, Brunswick), the area exhibits relatively few impacts when compared to other East Coast regions. However, threats from development need to be addressed with plans for environmentally compatible development <u>before</u> degradation occurs.

GEORGIA AND SOUTH CAROLINA STEWARDSHIP OF ESTUARINE AREAS

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Within the past 20 years, the legislatures of Georgia and South Carolina have taken some dramatic steps to protect and wisely allocate the resources of their respective estuarine areas. Pressures are and will always be present to alter the natural condition and functions of these areas. However, the casual attitudes and policies of governments of the past will never be left unchallenged again. The writer believes that citizens of these states and of the Nation generally have finally accepted and have at least a rudimentary appreciation of the importance of the holistic functioning of natural wetland systems. In mid 1988, it is not claiming too much to say that the average level of citizen understanding of wetland ecological "facts" will virtually guarantee rejection of broadscale alteration of these critical areas. Such a bold assertion rests on many presuppositions such as trust in rational decison-making by all levels of government, absence of national emergencies such as war, substantial curtailment of oil imports and other events that create or appear to create "either/or" circumstances where the integrity of large wetland areas are balanced against what are perceived as basic human interests. Then there is always the potential for greed and avarice.

While citizens of both States have couched their arguments in various terms, the struggle for control of estuarine areas is essentially between those who recognize only traditional private property use limitations and those who claim that these areas have always been and ought to be held and administered so as to reflect their important and distinctive public attributes.

The debate is national in scope. States such as California, where rampant wetland alteration activities have already irrevocably damaged a significant portion of that State's wetland resources, are in the forefront in rethinking their relaxed disregard of the importance of these natural systems. The "public trust" is the term used most often to indicate the body or bundle of rights the public has in these intertidal and wetland areas. Whether such claimed public rights are recognized as being derived from ancient property law concepts, statutes or recent judicial opinions, the interests sought to be protected or the limitations on private property rights relate to or have to do with the natural functioning of wetland systems. Persons claiming ownership rights often take the position that the property is theirs to use as they see fit - with only the most traditional zoning type limitations on their activities. Persons interested in fostering and promoting public rights in these areas often resort to the "bundle-of-sticks" analogy. This approach sees the totality of one's rights in properity as a bundle of sticks and recognizes that a particular tract can be conveyed with some of the sticks removed - which is what happened, they claim, before wetland areas were conveyed. Those sticks representing the public or "spill over" values of wetlands were removed and are now held in trust for the general benefit of the public. This reduction happened by action of the English Crown in pre-revolutionary days or by the respective states subsequent to that time. It is this distinction between wetland and intertidal property rights that is the source of the tension between private property title claimants and those asserting the public's rights.

Over the past 15 or so years court rulings in a series of cases in varied jurisdictions reveal judicial acceptance of a variety of limitations on harmful alterations of wetlands. These cases demonstrate that courts will uphold as constitutional statues, ordinances and regulations whose primary purpose is to prevent harm to the public or to public interests. The focus of judicial inquiry is increasingly directed toward the declared purposes of such limitations rather than on how severely claimed private property interests are affected. The courts are concerned with ecological attributes of these critical areas and are belately making new use of an old common law maxim that pre-dates the settlement of this continent by Europeans - "Sic utere tuo ut alienum non laedas" - (Use your own property in such manner as not to injure that of another). Increasingly, negative impacts of private uses "spilling over" into the public domain or adversely affecting public rights are legitimately prohibited.

The increasing willingness of the judiciary to recognize and protect rights of the public in waters and wetlands was rather starkly demonstrated in the recent case before the California Supreme Court, a jurisdiciton employing the prior appropriation water allocation scheme. In the <u>National Audubon Society vs. Superior Court of Alpine County</u> case, the court upset an established water diversion practice under which Los Angeles secures a significant portion of its water needs. Even though the water withdrawal permits were 40 years old and the city had expended millions on diversion and transmission facilities, the court said the State as sovereign retains continuing supervisory control over its navigable waters and the lands beneath those waters. The court allowed reconsideration of the withdrawal permits so that present ecosystem impacts could be addressed and ameliorated if necessary. Among other implications, the case illustrates the pivotal role governments have to view wetland systems as functioning ecological components of the public domain. While one must be cautious about extrapolating too directly to Georgia and South Carolina from such "foreign" situations, case law in these two States provides ample latitude for predicting similar local responses to similar egregious circumstances. Because population related pressures have so pervasively affected natural systems in California, it is not unexpected that citizens of that State have had to face natural resource limitations much earlier than some other states. In the context of concern for water and wetland resources, that State has been the most innovative in expanding and developing the many facets of the public trust doctrine. California's experience in this area is instructive of what is potentially available in other jurisdictions--especially those with more direct historical common law roots--such as Georgia and South Carolina.

South Carolina was historically slow to adopt estuarine area protection legislation. As a consequence, there was a period of significant tideland modification and marshland destruction. However, in terms of modern, integrated land use planning in its coastal zone, that State has taken a much more enlightened position than its neighboring State, Georgia. Its different political climate and the absence of some of the constitutional strictures existing in Georgia resulted in South Carolina securing approval for its coastal management program under the Federal Coastal Zone Management Act of 1972. In contrast, Georgia elected not to participate primarily for four reasons: (1) the existence of a powerful and persuasive, if not always candid, land development lobby; (2) tentative and halting natural resources adminstrative leadership; (3) certain "Home-Rule" constitutional provisions; and (4) a 1970 State statute imposing relatively strigent restrictions on estuarine area alteration or destruction.

Notwithstanding these slow starts of provincial attitudes, both States are presently acting seriously to protect intertidal and marshland resources. In both States, these advances were made from the citizen level up--rather than having been initiated by the natural resources protection leaders themselves. One of the implications of this fact is that consistent vigilance is necessary to maintain and develop the conservation advances already accomplished. Also, one must remember that an important reason we have vast expanses of intertidal wetlands and beautiful barrier island resources in both States is because historically large segments of these resources have been under the trusteeship of private claimants and owners. We owe much of our conservation heritage in these areas to such private holders. One has only to observe the recent history of state ownership and management practices to appreciate the role of private protection and application of public trust limitations. It is almost beyond serious argument that state ownership of some of the barrier islands has been a key element in their deterioration.

In both States, there is ample case law demonstrating judicial acceptance of imposition of public trust limitations and duties on governments. One examining these limitations will discover that we still labor with ancient legal theories and political shenanigans through which the English Crown solidified its control over intertidal and other lands. Historically these limitations were imposed on the original English colonies and were accepted as law of the states after the revolution against the Crown. Notwithstanding this significant body of legal precedent and its modern acceptance, there remains tremendous, continuing tension between traditional tideland claimants and the respective states. This conflict is much more intense in South Carolina than in Georgia and was the origin of a provision in South Carolina's Coastal Zone Management Act waiving immunity for the purpose of quieting title between citizens and the State.

In both States, the general rule on conveyance of intertidal lands from the Crown or a state is that grants of lands without specific reference to the "low water mark" conveyed title only to the mean "high water mark." While the issue is still bitterly contested, even when a grant is sufficiently specific to grant land to the low water mark, various applications of the public trust doctrine impose limitations on what such an owner can do in these intertidal areas. It is clear that such owners have exclusive rights to shellfish, for wharfing out and for any legal alterations of the bottoms that may be permitted. But public rights such as various forms of recreation, passage or navigation, fishing, and a potentially expandable list of use rights remain.

The famous or infamous Cape Romain case, in which the "high water-mark" rule was laid down, and its progeny are variously used by both major antagonists in this controversy in South Carolina. The contest is dynamic, and the writer believes it will require generations for a "solution" to evolve. This developing solution will no doubt occur as expectations change and as compromises and accommodations blunt the more intense and publicly visible instances of disappointment and frustration.

The South Carolina supreme court introduces confusion [Wyche, 1978(a)] when it appears to use the terms "tidal" and "navigable" synonymously. The implications of this lack of clarity have to do with the extent of conveyances bordering tidelands. If the prima facie rule has truly been acceptd by the court there is a presumption that the State owns intertidal lands adjacent to tracts bordered by tidal waters. The Cape Romain case could be read literally to apply an additional requirement of navigability in fact [Wyche, 1978(a)]. However, in cases subsequent to Cape Romain, there are ample holdings to the contrary sufficient to persuade that the prima facie rule is the law in South Carolina.

There are strong dissenting judicial and landowner opinions in South Carolina that any trust obligations that do exist apply only to submerged lands, i.e., below the mean low water mark. Others argue that accumulation of common law history, provisions of the State constitution, litigation reports and statutory law combine to persuade one that the majority view existent in the

Nation is the correct view for South Carolina, i.e., the State holds the intertidal lands, or the foreshore, in trust for the people [Wyche, 1978(a)]. The State is presently acting as if that view is the official one. Proponents of this view argue that the scope of limitations imposed by the trust include a broad range of important public rights or uses--other than the traditional uses of navigation, fishing, etc. This view has been accepted by the courts in other states.

Controversy remains in South Carolina and other states over what, if any, public rights remain after the state conveys an intertidal tract. In this unsettled area of the law, there are three general responses: (1) no alienation of public trust lands; (2) legitimate conveyance of only certain, narrow private use interests with the public's rights reserved; and (3) conveyance of both private and public attributes of title in circumstances where such transfer enhances the purposes of the trust and does not impair substantially the public interest in the lands and water remaining. While it is not entirely without doubt, South Carolina probably is in this third category [Wyche, 1978(a)].

In 1977 South Carolina enacted its Coastal Zone Management Act, SCCZMA, thus qualifying for approval under the Federal statutory program. The SCCZMA is an important step in the direction of estuarine area protection. The general scheme is the establishment of a broadly representative adminstrative body or Council to implement the coastal zone management program and to exercise direct regulatory control over certain activities within specified critical areas of the State as follows:

1. Coastal waters;
2. Tidelands;
3. Beaches; and
4. Primary ocean front sand dunes.

The SCCZMA includes a list of factors the Council must consider in determining whether to approve or deny an application. There is a requirement to develop a comprehensive management program for the state's coastal zone--which is the heart of the concept of imposing some controls in this area of the state [Wyche, 1978(b)].

Based on reports from practitioners "on the ground" in South Carolina, it is the writer's understanding that the management process is achieving acceptance and success in that State. If South Carolina remains committed to the goals and processes of the Federal CZMA, it will be a vast change for the better when compared to the situation that existed prior to the adoption of the SCCZMA.

The coastal zone management situation is a little different in Georgia. As mentioned earlier, in a battle among special interests, those desiring to defeat comprehensive, modern land use management in Georgia's coastal zone, combined with weak State leadership, were successful in preventing that State from participating in the Federal Coastal Zone Management Program. However, the State has generally been much more rigid in opposition to marshland destruction than has South Carolina. The qualifying word "generally" is used here because there is a disturbing little thread of inconsistencies in responses by the Georgia Department of Natural Resources (DNR), to applications to alter marshlands under that State's Marshland Protection Act, MPA. It is true that, with the exception the I-95 highway right-of-way marsh destruction. The Marshland Protection Committee (MPC) has been vigilant to prohibit or minimize instances of marsh destruction. But if one were to examine the entire performance second of the MPC, administratively a sub-unit of the DNR, one would discover permitted activities, mostly on a relatively small scale, that tend to set precedents or establish expectations on the part of later applicants that the State can ill afford to accommodate. It is difficult or impossible to assess the motivations of the authorities in circumstances where they have yielded to special development interests. It is equally difficult to see a rational pattern in these departures. This much seems clear--basically the regulation of marsh land destruction is an exercise in politics. Of course, there is some "law" involved, but like all environmental protection options, it operates essentially in a political context. And, in this context, even the stalwart sometimes feel they have to yield. It is everlastingly to the credit of the scientist types who staff the Marshland Protection Division of the DNR that the politics that beset the DNR generally have not bankrupted the entire marshland protection scheme.

In the late 1960's a proposal was made to mine the phosphate underlying the marshes of Chatham County around Savannah. This and related threats provided the impetus for enactment of the Coastal Marshland Protection Act of 1970. The statute and regulations prohibit the alteration of marshlands in the estuarine areas of the state which are defined as those lands supporting certain types of vegetation in tidally influenced waters lying within a tide-elevation range from 5.6 feet above mean tide level and below.

Applicants may appear before the MPC to present their proposals. The MPC hearing process is very informal and often subjective. The staff presents the applicants proposal to the Committee with a recommendation for approval or denial. In practice generally, if an applicant can not secure a positive recommendation from the MPC staff, the application is in trouble. Essentially the most important contact with "officialdom" an applicant makes is with the MPC staff. It is this stage in the process of an application that a form of negotiating occurs in which what the MPC will allow is discovered. When the staff recommends approval, its presentation takes on some characteristics of advocacy. When it recommends denial, it is a formidable adversary.

Though not pointedly directed to protect the usual estuarine-wetland resources, Georgia's Shore Assistance Act of 1979 addresses what is terms a "... vital natural resource system known as the sand-sharing system ..." and that this system is a "vital area" of the State. This expansive legislative finding and statement of purpose relates additionally to the state's constitutional provision for protection of "vital areas."

The general scheme of the Shore Assistance Act, the very name of which is an example of legislative euphemistic pandering to the development lobby, is to control modifications of and structures in nearshore waters and in the area of dynamic dune fields. It attempts to protect the "sand-sharing system" which it defines as an interdependent sediment system composed of sand dunes, beaches, and offshore bars and shoals.

Whether by design or neglect, neither the Georgia courts nor the legislature have, in express terms, embraced the public trust doctrine as a protective management scheme or property concept as has occurred in California and other jurisdictions where widespread environmental degradation is the norm. However, the State has accomplished much of the protections other states have provided pursuant to explicit acceptance of the "public trust" through evolutionary constitutional and statutory development such as the Coastal Marshland Protection Act, the Shore Assistance Act and the constitutional provision dealing with vital areas. And it is unlikely in the foreseable future that the courts in Georgia will use the traditional statement of the public trust as a sole basis for estuarine area and wetland protection. Rather, it is probable that case law will evolve within the bounds of the political consensus that has found expression in the two statutes and the constitutional provision mentioned above.

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ACTIVITIES OF THE FISH AND WILDLIFE SERVICE IN COASTAL SOUTH CAROLINA AND GEORGIA

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The Fish and Wildlife Service is actively involved in management, protection and enhancement of natural resources in coastal South Carolina and Georgia. These activities can be broadly categorized in our roles as resource managers and as regulatory review agents. The most visible resource management activities are carried out on wildlife refuges while the regulatory activities are the primary responsibility of our Fish and Wildlife Enhancement Offices. Additionally, the Service is involved in law enforcement activities on and off refuge lands, fish and wildlife research and anadromous fisheries management. Although much of our management effort is confined to refuge lands, most, if not all, of our activities are done in close coordination and cooperation with other state and Federal resource agencies responsible for these valuable coastal resources.

Resource Management

Within the estuarine zone of South Carolina and Georgia the Fish and Wildlife Service manages a total of eight wildlife refuges. The largest of these is Cape Romain which lies about 20 miles north of Charleston and the remaining seven are located about 120 miles south and are part of the Savannah Refuge complex. The diversity of management efforts exercised on these coastal management units demonstrates what man in harmony with nature can do to further multiple-use of these coveted resources.

Cape Romain National Wildlife Refuge, established in 1932, stretches for 22 miles along the coast of Charleston County, South Carolina. The refuge encompasses 34,229 acres of marsh, barrier islands, tidal creeks, and bays. An adjacent area of 30,000 acres of open water is closed by Presidential Proclamation to the taking of migratory birds. A 28,000 acre area is preserved within the National Wilderness Preservation System.

The estuarine marshes and their tidal mud flats are host to numerous waterfowl species, shorebirds, shellfish, and crabs. The saltwater bays and contain feature porpoises, scoters and many species of marine fishes. Brown pelicans and other colonial birds nest on the scattered islands. Although important for wintering waterfowl, the primary function of the Cape Romain Refuge is the production and protection of shore and wading birds. In 1987, for example the refuge supported 3,000 pelican nests and 8,000 to 12,000 tern nests. The beaches of Cape Island are intensively used by nesting loggerhead sea turtles. Freshwater impoundments support populations of waterfowl, American alligators, and freshwater fishes. Upland areas, particularly Bulls Island, provide habitat for fox squirrels, raccoons, white-tailed deer, and diverse bird species.

Cape Romain's rich history contains legends of Indians, pirates, and other early seafarers. Bulls Island, the largest land mass within the refuge, boasts a reputation as having been a favorite pirate hideway. The Sewee Indians once roamed the islands and waters in search of shellfish and game. The ocean, more than, man, continues to influence the refuge. Tides and winds build new islands and destroy others in a continual process that through the ages has greatly rearranged the shape of the land. The land is shaped by man, to a lesser degree. While much remains in an unaltered, natural state for wildlife, wildlife management practices alter the habitat to encourage maximum wildlife populations and use. These practices, like maintaining openings in the forest, controlling plants in impoundments which do not benefit wildlife, and controlling impoundment water levels help maintain habitat conditions and wildlife populations at optimum levels.

The most significant management activity presently being conducted in the refuge is the Loggerhead Turtle Nesting Project. Without this project 80-90% of all the nests would be destroyed either from predation by raccoons or beach erosion. During the 1988 nesting season the refuge will hire two crews who will work to protect more nests and to allow more young turtles to return to the ocean. Their efforts involve relocating eggs from the natural nests to a hatchery facility located on high ground near the beach. Shortly after hatching, the young turtles are returned to the surf and released. Hatching success in the hatchery is about 83%, but without the hatchery almost no young would return to the ocean. In 1987 Cape Romain supported 1176 turtle nests which represented 40% of the 2,957 nests that occured in all of South Carolina. This has been an extremely effective project through the year and one the Service hopes will continue to receive public recognition and adequate funding.

The newest project on Cape Romain Refuge involves the reintroduction of the endangered red wolf on Bulls Island. If successful the red wolf will be the first species that has become extinct in the wild and to be returned to the wild. The present plans are to let the pair that was recently put on the island to become acclimated in a near-natural holding pen and to rear young before they are actually released. This pair represents two of the only 92 red wolves left in the world. Red wolves were extirpated from South Carolina by 1850. Bulls Island has the necessary conditions to enhance the chances of the reintroduction being a success. It is a large island with minimal human encroachment and an abundant food source. The extensive news media coverage this activity has generated in coastal South Carolina clearly demonstrates the interest and support the public has for protecting and enhancing natural resources.

In addition to management efforts that are of interest to the general public, Cape Romain provides a number of opportunities for direct public involvement. Its 9 miles of undisturbed beaches provide swimming and fishing recreation while the marshes and freshwater impoundments provide opportunities for fishing and wildlife observation. The maritime forest on Bulls Island provides deer hunting, hiking and other nature-oriented activities.

Ongoing Fish and Wildlife activities and programs on Cape Romain are elaborated here to demonstrate how an agency like the Service can manage a fragile estuarine resource while at the same time allowing it to perform its natural functions as well as provide public recreation and enjoyment.

The Savannah Refuge complex is located nearly 120 miles south of Cape Romain. This complex is composed of seven individual refuges, two of which are in South Carolina and five in Georgia [Pinckney Island (S.C.); Savannah (S.C.); Tybee (GA); Wassaw Island (GA); Harris Neck (GA); Blackbeard Island (GA) and Wolf Island (GA)]. The Savannah Refuge is the largest unit in the complex comprising about 27,000 acres of freshwater marsh and forested wetlands. Much of the managment on the refuge is conducted for the purpose of providing wintering waterfowl habitat. Most of the impoundments on the refuge were once part of an old rice plantation. Although some of the dikes were constructed as long as 200 years ago, they have been maintained or restored through the years and are still functioning units where water levels can be manipulated and controlled as desired.

Although both Savannah and Cape Romain refuges are considered to be coastal units, there is an interesting contrast that influences how they are managed by the Service. Whereas Cape Romain is surrounded by a totally intertidal saltwater system, Savannah Refuge is located totally within intertidal freshwater wetlands. Another extremely noticeable contrast is the difference in the degree of being pristine. Cape Romain is within a relatively pristine natural setting, while Savannah Refuge is located adjacent to a major harbor and within view of a major city. Although the basic purpose of managing the two refuges is similar, the degree of effort that must be exerted on Savannah Refuge is much greater. Pressures resulting from human encroachment and water and air quality problems make it a constant struggle to maintain the habitat quality that is necessary for the refuge to fulfill its purpose of providing quality fish and wildlife habitat. The Fish and Wildlife Service is currently expending nearly $500,000 to conduct several studies to determine if the Savannah Harbor project has, or will, impact fish and wildlife resources on and around the refuge.

Analysis of the individual refuges within the Savannah Complex reveals that the degree of remoteness and pristineness ranges from the heavily human impacted Savannah Refuge to the virtually unimpacted pristine Blackbeard Island unit.

Each of the seven refuges in the Savannah complex are managed for the intended purposes of maximazing the natural resource qualities of the units while at the same time allowing a safe level of public involvement and utilization. Management activities conducted on the more remote refuges such as Blackbeard, Tybee, Wassaw, and Wolf Island are similar to those discussed earlier for Cape Romain Refuge.

In addition to refuge management activities being conducted in coastal Georgia and South Carolina, the Service is also involved in law enforcement, anadromous fish management, and fish and wildlife research activities. With only one law enforcement agent in each State the most intensive individual effort is expended on Service lands. Fish and Wildlife Service law enforcement activities on non-Service lands is extremely limited and can be accomplished only through a close cooperative effort with state enforcement agents.

Anadromous fish management in coastal Georgia and South Carolina is directed primarily toward the restoration of striped bass stocks. Again, in a joint effort with the States, the Service is rearing striped bass at our Orangeburg hatchery and at our Bears Bluff facility near Charleston. In an attempt to more effectively coordinate anadromous fish management efforts of the Service and the respective States, the Service has established an Anadromous Fish Coordinator position that is located in Charleston.

Research conducted by the Fish and Wildlife Service in these estuarine areas is done by the Fish and Wildlife cooperative units located at several major universities in the Southeast and by professional research biologists located in various laboratories around the country. An example of the kinds of research the coop units are doing is demonstrated by the efforts ongoing in the Savannah Harbor. Two separate coop units are looking at impacts of salinity changes on striped bass and how salinities influence long-term habitat changes.

They are also working closely with the Corps of Engineers to calibrate a salinity model that can be used to reliably estimate salinity changes that will result in the Savannah harbor not being deepening or being subjected to other habitat pertebations. Service research biologists are also monitoring contaminant build-up in various coastal river systems and collecting the necessary floral and faunal organisms to develop a baseline of data from which to work.

Regulatory Review

In addition to our role as Fish and Wildlife manager in coastal Georgia and South Carolina, the Service also plays an important role as a Federal Regulatory Agency. Our primary authority for this role is the Fish and Wildlife Coordination Act. Other authorities include NEPA, Endangered Species Act, Federal Clean Water Act, Section 10 of the River and Harbor Act, and Coastal Barrier Resources Act. The regulatory review role of the Service in coastal Georgia and South Carolina is directed primarily at "wetlands protection". Of the 5.2 million acres of coastal saltmarshes in the U.S., Georgia and South Carolina can boast of having more than 20% or about 1,000,000 acres. At the present time the rate of loss of intertidal saltmarsh in these two States is very low and should remain that way for the foreseeable future. The healthy state of affairs we are in with regard to wetlands protection is the result of combined and coordinated efforts of the various Federal and State permitting and regulatory review agencies. On the Federal scene the Fish and Wildlife Service, EPA and NMFS function as regulatory review agencies that provide input to the Corps of Engineers permit review process. From the State perspective the two permitting agencies that have contributed significantly to the healthy state of our coastal wetlands are the Georgia Marshlands Protection Group and the South Carolina Coastal Council. For the Fish and Wildlife Service to be effective in the regulatory review arena it is necessary that we coordinate closely with the various State entities as well as our Federal counterparts.

Relatively speaking, the estuarine system of Georgia and South Carolina is in a healthy condition. However, there are an increasing number of threats to the future health of this system and if vigilance and dedication to their protection is not maintained, the situation could quickly reverse itself. These future threats will require the the Service and the other State and Federal regulatory review agencies take full advantage of protective legislation and state-of-the-art science to assist in their efforts to protect and maintain a healthy system.

Potential threats to the system could come in various forms. One threat that cannot be overlooked is the ever increasing population shift from the inland segments of the country to the coastal sunbelt area. Along with the influx comes the relentless drive to buy and build waterfront and marshfront dwellings or whole developments. Support facilities such as roads, sewage treatment plants, and shopping centers are always an integral component of the waterward movement. In conjunction with such development there are desired ammenities such as boat ramps, marinas and golf courses. These kinds of threats, however, are fairly easy to protect against because the impacts are quite obvious. Whenever wetlands are filled, or dredged the detrimental impacts can be readily observed and quantified. Potential threats that we as regulatory review agencies need to be constantly on the alert for are those that are subtle and much more difficult to quantify. One such potential subtle threat involves the impounding of coastal wetlands for various purposes such as waterfowl impoundments, aquaculture, mariculture, and aesthetic ammenities to residential development.

South Carolina is unique with regard to the wetlands impoundment issue. Nearly 200 years ago South Carolina was the world leader in rice production. As a result nearly 140,000 acres of coastal wetlands were impounded, water control structures installed and water levels manipulated to encourage the growth of rice. Shortly after the Civil War this rice industry in S.C. collapsed, primarily because of the loss of slave labor to build new or maintain the existing facilities. In more recent times many plantation owners and/or concerned sportsman groups elected to restore many of the once functional rice impoundments for the purpose of creating wintering waterfowl habitat. Presently there are 70,000 acres of functionally impounded wetlands in South Carolina. Most of these are managed to provide wintering waterfowl habitat and the degree of management ranges from intensively managed to almost no active management. The remaining approximately 70,000 acres of previously impounded wetland now contain dike systems that are in various stages of disrepair. There are ever increasing pressures in South Carolina to reimpound these previously impounded areas to again make them functional and capable of regulating and manipulating water levels. Although some of the re-impoundment thrust is to creat wintering waterfowl habitat, the continual decline in Atlantic flyway waterfowl populations has reduced this thrust somewhat. The most potentially serious thrust to reimpound or even to build new impoundments will come from those interested in aquaculture and mariculture. As a regulatory review agency we are concerned about the potential threat the impounding of functional wetlands will or can have on the natural system. Most previously impounded areas are now subject to daily tidal fluctuations and are therefore an integral part of the natural system. Re-impounding or walling off of these systems disrupts the natural processes that normally take place.

If the quality of the estuarine system in Georgia and South Carolina is to be maintained it is imperative that regulatory review agencies such as the Service make biologically sound decisions. No decisions that could result in the irreversible alteration of the resources should be made unless thoroughly thought through and all the trade-offs evaluated.

There is cause for optimism that the estuarine resources in Georgia and South Carolina will remain healthy and as productive as they are today. It won't happen, however, if the Fish and Wildlife Service and other regulatory review agencies become complacent and take the matter for granted. Hard management choices will have to be made, but as long as the resource agencies make rational and sound biological decisions, the support for our efforts should continue.